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16. ABSTRACT

Standards of performance to control fugitive emissions of VOC from new, modified, and reconstructed Synthetic Organic Chemical Manufacturing Industry (SOCMI) plants are being proposed under Section 111 of the Clean Air Act. This document contains information on SOCMI, emission control technology for fugitive emissions of VOC, Regulatory Alternatives which were considered, analyses of environmental, energy, costs, and other technical data to support the standard of performance.

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VOC Fugitive Emissions in Synthetic Organic Chemicals Manufacturing Industry — Background Information for Proposed Standards

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

November 1980

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ENVIRONMENTAL PROTECTION AGENCY

Background Information and Draft Environmental Impact Statement for VOC Fugitive Emissions in Synthetic Organic Chemicals Manufacturing Industry

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1. The proposed standards of performance would limit emissions of volatile organic compounds from new, modified, and reconstructed units in the synthetic organic chemicals manufacturing industry. Section 111 of the Clean Air Act (42 U.S.C. 7411), as amended, directs the Administrator to establish standards of performance for any category of new stationary source of air pollution that ". . . causes or contributes significantly to air pollution which may reasonably be anticipated to endanger public health or welfare."

2. Copies of this document have been sent to the following: Federal Departments of Labor, Health and Human Services, Defense, Transportation, Agriculture, Commerce, Interior, and Energy; the National Science Foundation; the Council on Environmental Quality; members of the State and Territorial Air Pollution Program Administrators; the Association of Local Air Pollution Control Officials; EPA Regional Administrators; and other interested parties.

3. The comment period for review of this document is 75 days and is expected to begin on or about December 15.

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METRIC CONVERSION TABLE

In keeping with U.S. Environmental Protection Agency policy, metric units are used in this report. These units may be converted to common English units by using the following conversion factors:

Metric Unit	Metric Name	Equivalent English Unit
	LENGTH	
m	meter	39.3700 in.
m	meter	3.2810 ft.
	VOLUME	
l	liters	0.2642 U.S. gal
m^3	cubic meters	264.2 U.S. gal
m^3	cubic meters	6.29 Barrels (bbl)
	WEIGHT	
Kg	kilogram (10^3 grams)	2.2046 lb.
Mg	megagram (10^6 grams)	1.1023 tons
Gg	gigagram (10^9 grams)	1,102.3 tons
	ENERGY	
GJ	gigajoule	9.48×10^5 Btu
GJ	gigajoule	277.76 KWh
J/g	joule per gram	0.430 Btu/lb.
	VOLUMETRIC FLOW	
Nm^3/sec	normal cubic meters per second	2242 SCFM (ft^3/min)
	SPEED	
m/s	meters per second	196.86 ft/min

Temperature in degrees Celcius (°C) can be converted to temperature in degrees Farenheit (°F) by the following formula:

$$(°F) = 1.8\ (°C) + 32$$

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1.0 SUMMARY

1.1 REGULATORY ALTERNATIVES

Standards of performance for new stationary sources of volatile organic compounds (VOC) from fugitive emission sources in the Synthetic Organic Chemicals Manufacturing Industry (SOCMI) are being developed under the authority of Section 111 of the Clean Air Act. These standards would affect new stationary sources which produce as final products or intermediates one or more of certain organic chemicals. These standards would reduce emissions from pumps, compressors, valves, safety/relief valves, sampling connections, and open-ended lines.

Four regulatory alternatives were considered. Regulatory Alternative I is the baseline alternative and represents the level of control that would exist in the absence of any standards of performance. Requirements of Alternative II corresponds to the requirements of the Control Techniques Guidelines document (EPA-450/2-78-036) for petroleum refineries. These requirements are:

- Quarterly monitoring of all in-line valves, open-ended valves and safety/relief valves in gas service (relief valves would also be monitored after overpressure relieving to check for proper reseating);
- Annual monitoring of all in-line valves and open-ended valves in light liquid service;
- Quarterly monitoring of compressor seals;
- Annual monitoring of light liquid service pumps (such pumps would also be inspected visually for liquid leaks each week; immediate instrument monitoring of visually leaking pumps would be required); and
- Installation of caps, blinds, plugs, or second valves to seal all open-ended lines.

Regulatory Alternative III is more restrictive than Alternative II. Monthly rather than quarterly or annual monitoring would be required. Also, caps, plugs, or second valves would be required on open-ended lines, and weekly pump inspections as for Alternative II.

Of the four alternatives, Regulatory Alternative IV is the most restrictive. The requirements are:

- Monthly monitoring of all in-line valves and open-ended valves in gas and light liquid service;
- Installation of rupture disks upstream of gas service safety/relief valves that vent to the atmosphere (the disk would be replaced if disk failure were detected);
- Installation of closed vents and control devices for compressor seal area and/or degassing vents from compressor seal oil reservoirs;
- Installation of double mechanical seals on pumps in light liquid service and installation of closed vent control devices for degassing vents from seal oil reservoirs of all pumps in light liquid service (weekly visual inspections of pumps in light liquid service would also be required, with subsequent instrument monitoring required for those pumps with visible liquid leaks);
- Installation of closed loop sampling systems; and
- Installation of caps, blinds, plugs, or second valves to seal all open-ended lines.

1.2 ENVIRONMENTAL IMPACT

Fugitive emissions of VOC from affected SOCMI facilities would be 200 Gg/yr under Alternative I compared to 73, 62, and 26 Gg/yr under Alternatives II, III, and IV. Emissions reductions effected by Alternatives II, III, and IV would be 63, 69, and 87 percent, respectively.

In addition to reducing emission to the atmosphere, Alternatives II and III would reduce liquid leaks which might otherwise become a part of wastewater streams. Reduction of pollutants in effluents would also reduce wastewater treatment needs. Implementation of Alternative IV would also reduce liquid leaks, thereby reducing wastewater treatment needs. However, a small amount of wastewater containing suspened solids and some solid waste could result from the use of control systems required by Alternative IV. The impact of the wastewater and solid waste would be very small.

Energy savings would result under Regulatory Alternatives II, III, and IV. Under Alternative II, VOC's recovered during the fifth year of implementation would have an energy content of about 3,940 TJ. This heating value is equivalent to the heating value of 644,000 barrels of crude oil. VOC recovered under Alternative III in the fifth year would have a heating value of about 4,250 TJ which is equivalent to the heating value of 695,000 barrels of crude. The heating value of VOC recovered under Alternative IV would be 5,360 TJ. This is the same heating value found in 876,000 barrels of crude oil.

A more detailed analysis of environmental and energy impacts is presented in Chapter 7. A summary of the environmental and economic impacts associated with the four regulatory alternatives is shown in Table 1-1.

1.3 ECONOMIC IMPACT

Costs incurred by SOCMI under Regulatory Alternatives II and III would actually be credits due to the value of recovered VOC. In the fifth year after implementation of Alternative II, a net annualized credit of $29 million would result. For the same year under Alternative III, a net annualized credit of $21 million would result. Net annualized costs incurred during the fifth year under Regulatory Alternative IV would be $11 million. In this Alternative the costs exceed the value of recovered VOC. A more detailed analysis of costs is included in Chapter 8.

In general, most units will not increase product prices as a result of the implementation of Regulatory Alternatives II, III, or IV. A more detailed economic analysis is presented in Chapter 9.

Economic impacts associated with the four Regulatory Alternatives are shown in Table 1-1.

TABLE 1-1. ENVIRONMENTAL AND ECONOMIC IMPACTS OF REGULATORY ALTERNATIVES

Administrative Action	Air Impact	Water Impact	Solid Waste Impact	Energy Impact	Noise Impact	Economic Impact
Regulatory Alternative I (No Action)	0	0	0	0	0	0
Regulatory Alternative II	+2**	+1**	0	+1*	0	+1*
Regulatory Alternative III	+2**	+1**	0	+1*	0	+1*
Regulatory Alternative IV	+3**	+1**	0	+1*	0	-1*

KEY:
+ Beneficial impact
- Adverse impact
0 No impact
1 Negligible impact

2 Small impact
3 Moderate impact
4 Large impact

* Short-term impact
** Long-term impact
*** Irreversible impact

2. INTRODUCTION

2.1 BACKGROUND AND AUTHORITY FOR STANDARDS

Before standards of performance are proposed as a Federal regulation, air pollution control methods available to the affected industry and the associated costs of installing and maintaining the control equipment are examined in detail. Various levels of control based on different technologies and degrees of efficiency are expressed as regulatory alternatives. Each of these alternatives is studied by EPA as a prospective basis for a standard. The alternatives are investigated in terms of their impacts on the economics and well-being of the industry, the impacts on the national economy, and the impacts on the environment. This document summarizes the information obtained through these studies so that interested persons will be able to see the information considered by EPA in the development of the proposed standard.

Standards of performance for new stationary sources are established under Section 111 of the Clean Air Act (42 U.S.C. 7411) as amended, hereinafter referred to as the Act. Section 111 directs the Administrator to establish standards of performance for any category of new stationary source of air pollution which ". . . causes, or contributes significantly to air pollution which may reasonably be anticipated to endanger public health or welfare."

The Act requires that standards of performance for stationary sources reflect ". . . the degree of emission reduction achievable which (taking into consideration the cost of achieving such emission reduction, and any nonair quality health and environmental impact and energy requirements) the Administrator determines has been adequately demonstrated for that category of sources." The standards apply only to stationary sources, the construction or modification of which commences after regulations are proposed by publication in the Federal Register.

The 1977 amendments to the Act altered or added numerous provisions that apply to the process of establishing standards of performance.

1. EPA is required to list the categories of major stationary sources that have not already been listed and regulated under standards of performance. Regulations must be promulgated for these new categories on the following schedule:

   a. 25 percent of the listed categories by August 7, 1980.

   b. 75 percent of the listed categories by August 7, 1981.

   c. 100 percent of the listed categories by August 7, 1982.

A governor of a State may apply to the Administrator to add a category not on the list or may apply to the Administrator to have a standard of performance revised.

2. EPA is required to review the standards of performance every 4 years and, if appropriate, revise them.

3. EPA is authorized to promulgate a standard based on design, equipment, work practice, or operational procedures when a standard based on emission levels is not feasible.

4. The term "standards of performance" is redefined, and a new term "technological system of continuous emission reduction" is defined. The new definitions clarify that the control system must be continuous and may include a low- or non-polluting process or operation.

5. The time between the proposal and promulgation of a standard under Section 111 of the Act may be extended to 6 months.

Standards of performance, by themselves, do not guarantee protection of health or welfare because they are not designed to achieve any specific air quality levels. Rather, they are designed to reflect the degree of emission limitation achievable through application of the best adequately demonstrated technological system of continuous emission reduction, taking into consideration the cost of achieving such emission reduction, any nonair-quality health and environmental impacts, and energy requirements.

Congress had several reasons for including these requirements. First, standards with a degree of uniformity are needed to avoid situations where some states may attract industries by relaxing standards relative to other states. Second, stringent standards enhance the potential for long-term growth. Third, stringent standards may help achieve long-term cost savings by avoiding the need for more expensive retrofitting when pollution ceilings may be reduced in the future. Fourth, certain types of standards for coal-burning sources can adversely affect the coal market by driving up the price of low-sulfur coal or effectively excluding certain coals from the reserve base because their untreated pollution potentials are high. Congress does not intend that new source performance standards contribute to these problems. Fifth, the standard-setting process should create incentives for improved technology.

Promulgation of standards of performance does not prevent State or local agencies from adopting more stringent emission limitations for the same sources. States are free under Section 116 of the Act to establish even more stringent emission limits than those established under Section 111 or those necessary to attain or maintain the National Ambient Air Quality Standards (NAAQS) under Section 110. Thus, new sources may in some cases be subject to limitations more stringent than standards of performance under Section 111, and prospective owners and operators of new sources should be aware of this possibility in planning for such facilities.

A similar situation may arise when a major emitting facility is to be constructed in a geographic area that falls under the prevention of significant deterioration of air quality provisions of Part C of the Act. These provisions require, among other things, that major emitting facilities to be constructed in such areas are to be subject to best available control technology. The term Best Available Control Technology (BACT), as defined in the Act, means

> ". . . an emission limitation based on the maximum degree of reduction of each pollutant subject to regulation under this Act emitted from, or which results from, any major emitting facility, which the permitting authority, on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, determines is achievable for such facility through application of production processes and available methods, systems, and techniques, including fuel cleaning or treatment or innovative fuel combustion techniques

> for control of each such pollutant. In no event shall application of "best available control technology" result in emissions of any pollutants which will exceed the emissions allowed by any applicable standard established pursuant to sections 111 or 112 of this Act. (Section 169(3))

Although standards of performance are normally structured in terms of numerical emission limits where feasible, alternative approaches are sometimes necessary. In some cases physical measurement of emissions from a new source may be impractical or exorbitantly expensive. Section 111(h) provides that the Administrator may promulgate a design or equipment standard in those cases where it is not feasible to prescribe or enforce a standard of performance. For example, emissions of hydrocarbons from storage vessels for petroleum liquids are greatest during tank filling. The nature of the emissions, high concentrations for short periods during filling and low concentrations for longer periods during storage, and the configuration of storage tanks make direct emission measurement impractical. Therefore, a more practical approach to standards of performance for storage vessels has been equipment specification.

In addition, section 111(i) authorizes the Administrator to grant waivers of compliance to permit a source to use innovative continuous emission control technology. In order to grant the waiver, the Administrator must find: (1) a substantial likelihood that the technology will produce greater emission reductions than the standards require or an equivalent reduction at lower economic, energy, or environmental cost; (2) the proposed system has not been adequately demonstrated; (3) the technology will not cause or contribute to an unreasonable risk to the public health, welfare, or safety; (4) the governor of the State where the source is located consents; and (5) the waiver will not prevent the attainment or maintenance of any ambient standard. A waiver may have conditions attached to assure the source will not prevent attainment of any NAAQS. Any such condition will have the force of a performance standard. Finally, waivers have definite end dates and may be terminated earlier if the conditions are not met or if the system fails to perform as expected. In such a case, the source may be given up to 3 years to to meet the standards with a mandatory progress schedule.

2.2 SELECTION OF CATEGORIES OF STATIONARY SOURCES

Section 111 of the Act directs the Adminstrator to list categories of stationary sources. The Administrator ". . . shall include a category of sources in such list if in his judgement it causes, or contributes significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare." Proposal and promulgation of standards of performance are to follow.

Since passage of the Clean Air Amendments of 1970, considerable attention has been given to the development of a system for assigning priorities to various source categories. The approach specifies areas of interest by considering the broad strategy of the Agency for implementing the Clean Air Act. Often, these "areas" are actually pollutants emitted by stationary sources. Source categories that emit these pollutants are evaluated and ranked by a process involving such factors as: (1) the level of emission control (if any) already required by State regulations, (2) estimated levels of control that might be required from standards of performance for the source category, (3) projections of growth and replacement of existing facilities for the source category, and (4) the estimated incremental amount of air pollution that could be prevented in a preselected future year by standards of performance for the source category. Sources for which new source performance standards were promulgated or under development during 1977, or earlier, were selected on these criteria.

The Act amendments of August 1977 establish specific criteria to be used in determining priorities for all major source categories not yet listed by EPA. These are: (1) the quantity of air pollutant emissions that each such category will emit, or will be designed to emit; (2) the extent to which each such pollutant may reasonably be anticipated to endanger public health or welfare; and (3) the mobility and competitive nature of each such category of sources and the consequent need for nationally applicable new source standards of performance.

The Administrator is to promulgate standards for these categories according to the schedule referred to earlier.

In some cases it may not be feasible immediately to develop a standard for a source category with a high priority. This might happen when a program of research is needed to develop control techniques or because techniques for sampling and measuring emissions may require refinement. In the developing of standards, differences in the time required to complete the necessary investigation for different source categories must also be considered. For example, substantially more time may be necessary if numerous pollutants must be investigated from a single source category. Further, even late in the development process the schedule for completion of a standard may change. For example, inability to obtain emission data from well-controlled sources in time to pursue the development process in a systematic fashion may force a change in scheduling. Nevertheless, priority ranking is, and will continue to be, used to establish the order in which projects are initiated and resources assigned.

After the source category has been chosen, the types of facilities within the source category to which the standard will apply must be determined. A source category may have several facilities that cause air pollution, and emissions from some of these facilities may vary from insignificant to very expensive to control. Economic studies of the source category and of applicable control technology may show that air pollution control is better served by applying standards to the more severe pollution sources. For this reason, and because there is no adequately demonstrated system for controlling emissions from certain facilities, standards often do not apply to all facilities at a source. For the same reasons, the standards may not apply to all air pollutants emitted. Thus, although a source category may be selected to be covered by a standard of performance, not all pollutants or facilities within that source category may be covered by the standards.

2.3 PROCEDURE FOR DEVELOPMENT OF STANDARDS OF PERFORMANCE

Standards of performance must (1) realistically reflect best demonstrated control practice; (2) adequately consider the cost, the non-air-quality health and environmental impacts, and the energy requirements of such control; (3) be applicable to existing sources that are modified or reconstructed as well as new installations; and (4) meet these conditions for all variations of operating conditions being considered anywhere in the country.

The objective of a program for developing standards is to identify the best technological system of continuous emission reduction that has been adequately demonstrated. The standard-setting process involves three principal phases of activity: (1) information gathering, (2) analysis of the information, and (3) development of the standard of performance.

During the information-gathering phase, industries are queried through a telephone survey, letters of inquiry, and plant visits by EPA representatives. Information is also gathered from many other sources, and a literature search is conducted. From the knowledge acquired about the industry, EPA selects certain plants at which emission tests are conducted to provide reliable data that characterize the pollutant emissions from well-controlled existing facilities.

In the second phase of a project, the information about the industry and the pollutants emitted is used in analytical studies. Hypothetical "model plants" are defined to provide a common basis for analysis. The model plant definitions, national pollutant emission data, and existing State regulations governing emissions from the source category are then used in establishing "regulatory alternatives." These regulatory alternatives are essentially different levels of emission control.

EPA conducts studies to determine the impact of each regulatory alternative on the economics of the industry and on the national economy, on the environment, and on energy consumption. From several possibly applicable alternatives, EPA selects the single most plausible regulatory alternative as the basis for a standard of performance for the source category under study.

In the third phase of a project, the selected regulatory alternative is translated into a standard of performance, which, in turn, is written in the form of a Federal regulation. The Federal regulation, when applied to newly constructed plants, will limit emissions to the levels indicated in the selected regulatory alternative.

As early as is practical in each standard-setting project, EPA representatives discuss the possibilities of a standard and the form it might take with members of the National Air Pollution Control Techniques Advisory Committee. Industry representatives and other interested parties also participate in these meetings.

The information acquired in the project is summarized in the Background Information Document (BID). The BID, the standard, and a preamble explaining the standard are widely circulated to the industry being considered for control, environmental groups, other government agencies, and offices within EPA. Through this extensive review process, the points of view of expert reviewers are taken into consideration as changes are made to the documentation.

A "proposal package" is assembled and sent through the offices of EPA Assistant Administrators for concurrence before the proposed standard is officially endorsed by the EPA Administrator. After being approved by the EPA Administrator, the preamble and the proposed regulation are published in the Federal Register.

As a part of the Federal Register announcement of the proposed regulation, the public is invited to participate in the standard-setting process. EPA invites written comments on the proposal and also holds a public hearing to discuss the proposed standard with interested parties. All public comments are summarized and incorporated into a second volume of the BID. All information reviewed and generated in studies in support of the standard of performance is available to the public in a "docket" on file in Washington, D. C.

Comments from the public are evaluated, and the standard of performance may be altered in response to the comments.

The significant comments and EPA's position on the issues raised are included in the "preamble" of a "promulgation package," which also contains the draft of the final regulation. The regulation is then subjected to another round of review and refinement until it is approved by the EPA Administrator. After the Administrator signs the regulation, it is published as a "final rule" in the Federal Register.

2.4 CONSIDERATION OF COSTS

Section 317 of the Act requires an economic impact assessment with respect to any standard of performance established under Section 111 of the Act. The assessment is required to contain an analysis of (1) the costs of compliance with the regulation, including the extent to which the cost of compliance varies depending on the effective date of the regulation and the development of less expensive or more efficient methods of compliance, (2) the potential inflationary or recessionary effects of the regulation, (3) the effects the regulation might have on small business with respect to competition, (4) the effects of the regulation on consumer costs, and (5) the effects of the regulation on energy use. Section 317 also requires that the economic impact assessment be as extensive as practicable.

The economic impact of a proposed standard upon an industry is usually addressed both in absolute terms and in terms of the control costs that would be incurred as a result of compliance with typical, existing State control regulations. An incremental approach is necessary because both new and existing plants would be required to comply with State regulations in the absence of a Federal standard of performance. This approach requires a detailed analysis of the economic impact from the cost differential that would exist between a proposed standard of performance and the typical State standard.

Air pollutant emissions may cause water pollution problems, and captured potential air pollutants may pose a solid waste disposal problem. The total environmental impact of an emission source must, therefore, be analyzed and the costs determined whenever possible.

A thorough study of the profitability and price-setting mechanisms of the industry is essential to the analysis so that an accurate estimate of potential adverse economic impacts can be made for proposed standards. It is also essential to know the capital requirements for pollution control systems already placed on plants so that the additional capital requirements necessitated by these Federal standards can be placed in proper perspective. Finally, it is necessary to assess the availability of capital to provide the additional control equipment needed to meet the standards of performance.

2.5 CONSIDERATION OF ENVIRONMENTAL IMPACTS

Section 102(2)(C) of the National Environmental Policy Act (NEPA) of 1969 requires Federal agencies to prepare detailed environmental impact statements on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment. The objective of NEPA is to build into the decision-making process of Federal agencies a careful consideration of all environmental aspects of proposed actions.

In a number of legal challenges to standards of performance for various industries, the United States Court of Appeals for the District of Columbia Circuit has held that environmental impact statements need not be prepared by the Agency for proposed actions under Section 111 of the Clean Air Act. Essentially, the Court of Appeals has determined that the best system of emission reduction requires the Administrator to take into account counter-productive environmental effects of a proposed standard, as well as economic costs to the industry. On this basis, therefore, the Court established a narrow exemption from NEPA for EPA determination under Section 111.

In addition to these judicial determinations, the Energy Supply and Environmental Coordination Act (ESECA) of 1974 (PL-93-319) specifically exempted proposed actions under the Clean Air Act from NEPA requirements. According to section 7(c)(1), "No action taken under the Clean Air Act shall be deemed a major Federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969." (15 U.S.C. 793(c)(1))

Nevertheless, the Agency has concluded that the preparation of environmental impact statements could have beneficial effects on certain regulatory actions. Consequently, although not legally required to do so by section 102(2)(C) of NEPA, EPA has adopted a policy requiring that environmental impact statements be prepared for various regulatory actions, including standards of performance developed under section 111 of the Act. This voluntary preparation of environmental impact statements, however, in no way legally subjects the Agency to NEPA requirements.

To implement this policy, a separate section in this document is devoted solely to an analysis of the potential environmental impacts associated with the proposed standards. Both adverse and beneficial impacts in such areas as air and water pollution, increased solid waste disposal, and increased energy consumption are discussed.

2.6 IMPACT ON EXISTING SOURCES

Section 111 of the Act defines a new source as ". . . any stationary source, the construction or modification of which is commenced . . ." after the proposed standards are published. An existing source is redefined as a new source if "modified" or "reconstructed" as defined in amendments to the general provisions of Subpart A of 40 CFR Part 60, which were promulgated in the Federal Register on December 16, 1975 (40 FR 58416).

Promulgation of a standard of performance requires States to establish standards of performance for existing sources in the same industry under Section 111 (d) of the Act if the standard for new sources limits emissions of a designated pollutant (i.e., a pollutant for which air quality criteria have not been issued under Section 108 or which has not been listed as a hazardous pollutant under Section 112). If a State does not act, EPA must establish such standards. General provisions outlining procedures for control of existing sources under Section 111(d) were promulgated on November 17, 1975, as Subpart B of 40 CFR Part 60 (40 FR 53340).

2.7 REVISION OF STANDARDS OF PERFORMANCE

Congress was aware that the level of air pollution control achievable by any industry may improve with technological advances. Accordingly, Section 111 of the Act provides that the Administrator ". . . shall, at least every four years, review and, if appropriate, revise . . ." the standards. Revisions are made to assure that the standards continue to reflect the best systems that become available in the future. Such revisions will not be retroactive, but will apply to stationary sources constructed or modified after the proposal of the revised standards.

3. DESCRIPTION OF FUGITIVE EMISSION SOURCES

3.1 INTRODUCTION AND GENERAL INDUSTRY INFORMATION

3.1.1 Introduction

The primary purposes of this chapter are to define the synthetic organic chemical manufacturing industry (SOCMI) and describe the potential fugitive emission sources that are typically found in this industry. Where possible, the leak rates of uncontrolled emissions from the various potential fugitive emission sources are quantified. Industrial practices and state or local regulations that currently reduce fugitive emissions from the SOCMI are also briefly discussed in this chapter.

3.1.2 General Information

Organic chemicals are manufactured in a multi-leveled system of chemical processes that is based on about ten feedstock chemicals which are principally produced in petroleum refineries. These feedstocks then proceed through one or more of the process levels and result in literally thousands of intermediate or finished chemicals (see Figure 3-1). Generally, each process level contains more chemicals than the preceding level; the plants manufacturing the products are smaller than the plants supplying the feedstock; and the volatilities of the products are lower than the volatilities of the feedstocks. Because of the number and diverse nature of the organic chemicals included in the multi-leveled system, the organic chemical industry must be divided into segments for environmental study and regulation. The synthetic organic chemical manufacturing industry (SOCMI) is a readily recognizable segment consisting of some of the higher volume intermediate and finished products. SOCMI chemicals are the feedstocks for many of the industries producing synthetic products, such as plastics, fibers, dyes and synthetic rubber. A list of the SOCMI chemicals is presented in Appendix F.

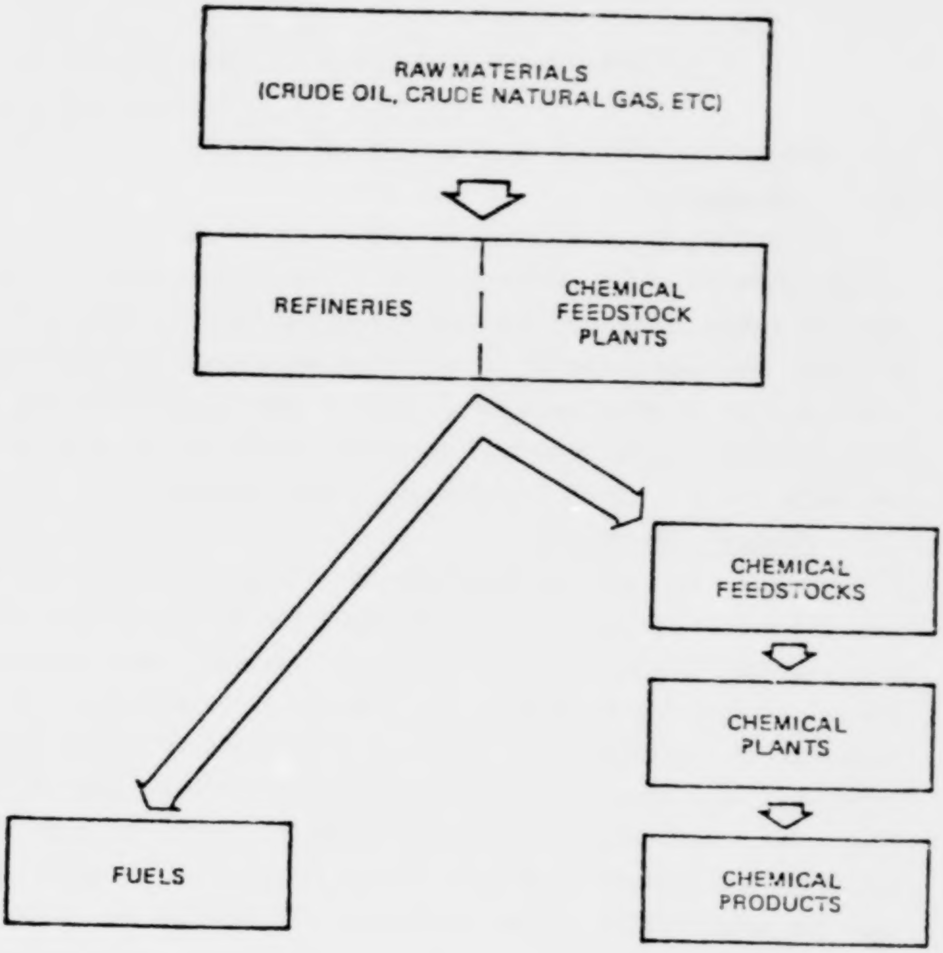
RAW MATERIALS
(CRUDE OIL, CRUDE NATURAL GAS, ETC)
REFINERIES
CHEMICAL FEEDSTOCK PLANTS
CHEMICAL FEEDSTOCKS
CHEMICAL PLANTS
CHEMICAL PRODUCTS
FUELS

Figure 3-1. General schematic of process levels that make up the organic chemical industry.

Although there are organic chemical manufacturing plants in most industrialized areas of the country, about 60 percent of the SOCMI volume is produced in Texas and Louisiana. Each plant site may manufacture from one to several organic chemicals using one or more processes. Although most processes result in one basic product, some produce a family of chemicals. Conversely, many chemicals are produced by more than one process. Yearly, production quantities at each plant can range from a few million to several billion kilograms.

3.2 FUGITIVE EMISSION DEFINITION AND POTENTIAL SOURCE DESCRIPTION

3.2.1 Definition

In this study, fugitive emissions in the SOCMI are considered to be those volatile organic compound (VOC) emissions that result when process fluid (either liquid or gaseous) leaks from plant equipment. Those VOC emissions resulting from the transfer, storage, treatment, and/or disposal of process wastes will be covered by other standards.

3.2.2 Potential Source Characterization and Description

There are many potential sources of fugitive emissions in a typical synthetic organic chemical plant. The following sources will be considered in this chapter: pumps, compressors, in-line process valves, pressure relief devices, open-ended valves, sampling connections, flanges, agitators, and cooling towers. Fugitive emissions which result from leaks in these types of equipment are generally random occurences which cannot be predicted. Leak occurence is independent of temperature, pressure, and other process variables but shows a correlation with vapor pressure of the substance in the line. These potential sources are described below.

3.2.2.1 Pumps. Pumps are used extensively in the SOCMI for the movement of organic liquids.[1] The centrifugal pump is the most widely used pump in the SOCMI; however, other types, such as the positive-diaphragm pumps, are also used in this industry. Chemicals transfered by pumps can leak at the point of contact between the moving shaft and stationary casing. Consequently, all pumps except the sealless type (canned-motor and diaphragm) require a seal at the point where the shaft penetrates the housing in order to isolate the pump's interior from the atmosphere.

Two generic types of seals, packed and mechanical, are currently in use on pumps in the SOCMI. Packed seals can be used on both reciprocating and rotary action types of pumps. As Figure 3-2 shows, a packed seal consists of a cavity ("stuffing box") in the pump casing filled with special packing material that is compressed with a packing gland to form a seal around the shaft. Lubrication is required to prevent the buildup of frictional heat between the seal and shaft. The necessary lubrication is provided by a lubricant that flows between the packing and the shaft.[2] Deterioration of the packing will result in process liquid leaks.

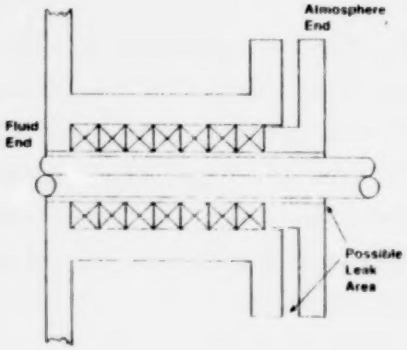

Figure 3-2. Diagram of a simple packed seal.[3]

Mechanical seals are limited in application to pumps with rotating shafts and can be further categorized as single and dual mechanical seals. There are many variations to the basic design of mechanical seals, but all have a lapped seal face between a stationary element and a rotating seal ring.[4] In a single mechanical seal application (Figure 3-3), the rotating-seal ring and stationary element faces are lapped to a very high degree of flatness to maintain contact throughout their entire mutual surface area. The faces are held together by a combination of pressure supplied by a spring and the pump pressure transmitted through the liquid which is being pumped. An elastomer seals the rotating face to the shaft. The stationary face is sealed to the stuffing box with another elastomer or gasket.

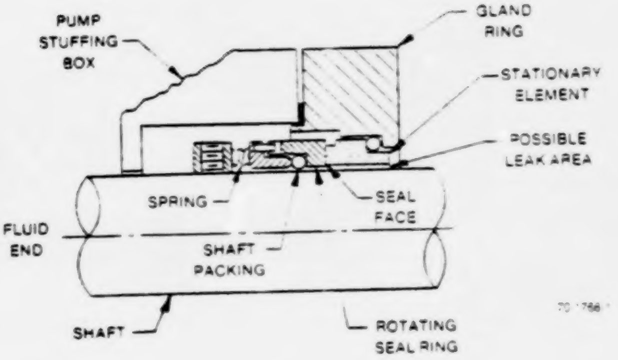

Figure 3-3. Diagram of a basic single mechanical seal.[5]

In a dual mechanical seal application, two seals are usually arranged back-to-back or in tandem. In the back-to-back arrangement (Figure 3-4), the two seals provide a closed cavity between them. A seal liquid, such as water or seal oil, is circulated through the cavity. Because the seal liquid surrounds the two seals, it can be used to control the temperature in the stuffing box. In order for the seal to function, the seal liquid must be at a pressure greater than the operating pressure of the stuffing box. As a result, any leakage would be across the seal faces. Liquid leaking across the inboard face would enter the stuffing box and mix with the process liquid. Seal liquid going across the outboard face would exit to the atmosphere. Therefore, the seal liquid must be compatible with the process liquid as well as with the environment.[6]

In a tandem dual mechanical seal arrangement (Figure 3-5), the seals face the same direction. The secondary seal provides a backup for the primary seal. The cavity between the two seals is filled with a buffer liquid which may be used for temperature control in the stuffing box. However, the barrier liquid may be at a pressure lower than that in the stuffing box. Therefore, any leakage would be from the stuffing

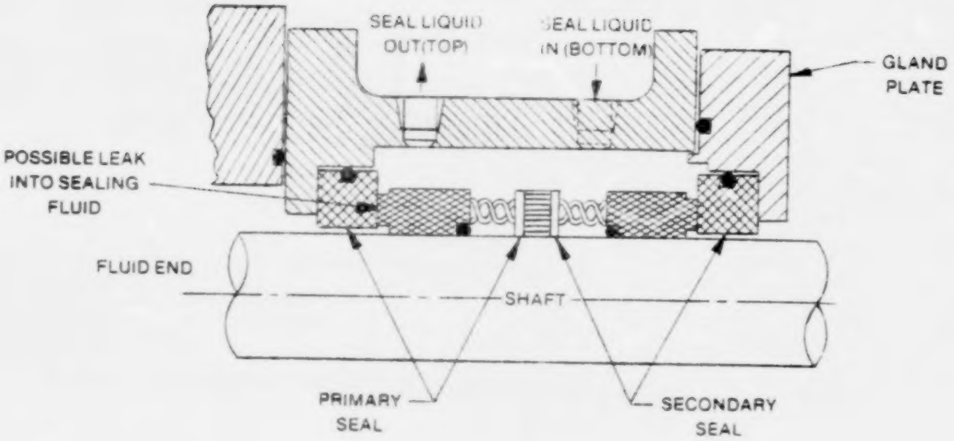
SEAL LIQUID OUT(TOP)
SEAL LIQUID IN (BOTTOM)
GLAND PLATE
POSSIBLE LEAK INTO SEALING FLUID
FLUID END
SHAFT
PRIMARY SEAL
SECONDARY SEAL

Figure 3-4. Diagram of a dual mechanical seal (back-to-back arrangement).[7]

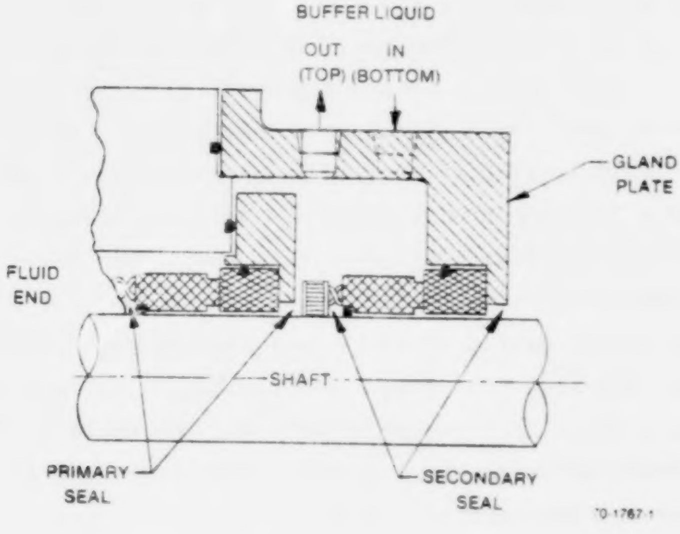
BUFFER LIQUID
OUT (TOP)
IN (BOTTOM)
GLAND PLATE
FLUID END
SHAFT
PRIMARY SEAL
SECONDARY SEAL
70-1767-1

Figure 3-5. Diagram of a dual mechanical seal (tanden arrangement).[8]

box into the barrier liquid. Since this liquid is routed to a closed reservoir, process liquid that has leaked into the seal cavity will also be transferred to the reservoir. At the reservoir, the process liquid could vaporize and be emitted to the atmosphere. To ensure that VOC's do not leak from the reservoir, the reservoir can be vented to a control device.[9]

Another arrangement of dual seals which represents a relatively new development is the face-to-face arrangement. In this configuration two rotating faces are mated with a common stationary. Barrier fluid may be provided at higher or lower pressures than the stuffing box. As in the tandem arrangement, if the barrier fluid is at a lower pressure than the stuffing box, the barrier fluid reservoir would require venting to a control device.

Another type of pump that has been used in the chemical industry is the sealless pump. Canned-motor and diaphragm pumps are sealless pumps. In the canned-motor pumps the cavity housing the motor rotor and the pump casing are interconnected. As a result, the motor bearings run in the process liquid and all seals are eliminated. Because the process liquid is the bearing lubricant, abrasive solids cannot be tolerated. Canned-motor pumps are being widely used for handling organic solvents, organic heat transfer liquids, light oils, as well as many toxic or hazardous liquids, or where leakage is an economic problem.[10]

Diaphragm pumps (see Figure 3-6) perform similarly to piston and plunger pumps. However, the driving member is a flexible diaphragm

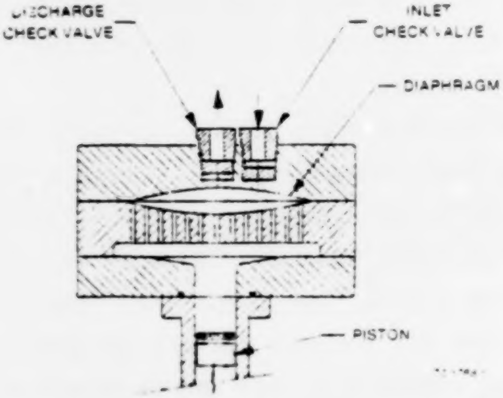

Figure 3-6. Diaphragm Pump[12]

fabricated of metal, rubber, or plastic. The primary advantage of this arrangement is the elimination of all packing and seals exposed to the process liquid. This is an important asset when hazardous or toxic liquids are handled.[11]

3.2.2.2 Compressors. Gas compressors used in the SOCMI are similar to pumps in that they can be driven by rotary or reciprocating shafts. They are also similar to pumps in their need for shaft seals to isolate the process gas from the atmosphere. As with pumps, these seals are likely to be the source of fugitive emissions from compressors.

Shaft seals for compressors may be chosen from several different types: labyrinth, restrictive carbon rings, mechanical contact, and liquid film. All of these seal types are leak restriction devices; none of them completely eliminates leakage. Many compressors may be equipped with ports in the seal area to evacuate gases collecting there.

The labyrinth type of compressor seal is composed of a series of close tolerance, interlocking "teeth" which restrict the flow of gas along the shaft. A straight pass labyrinth compressor seal is shown in Figure 3-7. Many variations in "tooth" design and materials of construction are available. Although labyrinth type seals have the largest leak potential of the different types, properly applied variations in "tooth" configuration and shape can reduce leakage by up to 40 percent over a straight pass type labyrinth.[13]

Restrictive carbon ring seals consist of multiple stationary carbon rings with close shaft clearances. This type of seal may be operated dry with a sealing fluid or with a buffer gas. Restrictive ring seals can achieve lower leak rates than the labyrinth type.[14] A restrictive ring seal is shown in Figure 3-8.

Mechanical contact seals (shown in Figure 3-9) are similar to the mechanical seals described for pumps. In this type of seal clearance between the rotating and stationary elements is reduced to essentially zero. Oil or another suitable lubricant is supplied to the seal faces. Mechanical contact seals can achieve the lowest leak rates of the types described here, but they are not suitable for all processing conditions.[15]

Centrifugal compressors also can be equipped with liquid film seals. A diagram of a liquid film seal is shown in Figure 3-10. The seal is formed by a film of oil between the rotating shaft and stationary gland.

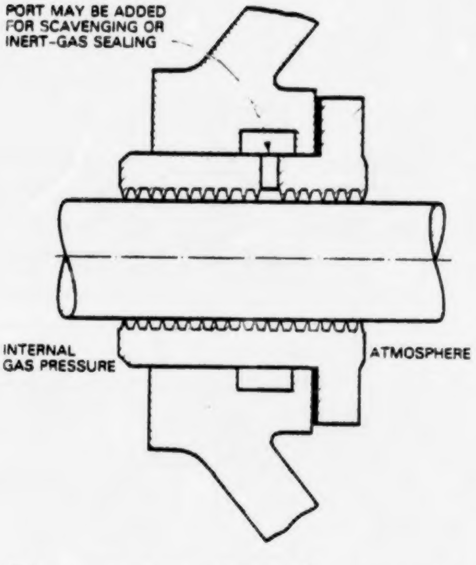
PORT MAY BE ADDED
FOR SCAVENGING OR
INERT-GAS SEALING
INTERNAL
GAS PRESSURE
ATMOSPHERE

Figure 3-7. Labyrinth compressor seal.*

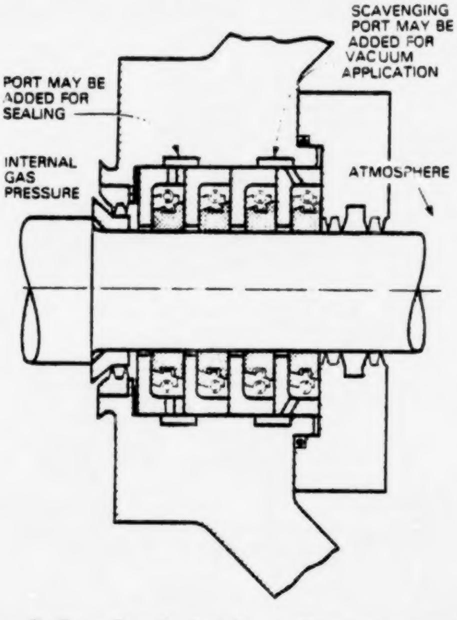
SCAVENGING
PORT MAY BE
ADDED FOR
VACUUM
APPLICATION
PORT MAY BE
ADDED FOR
SEALING
INTERNAL
GAS
PRESSURE
ATMOSPHERE

Figure 3-8. Restrictive ring compressor seal.*

*American Petroleum Institute. Centrifugal Compressors for Refinery Service, API Standard 617, 4th ed., pp. 8-9. Reprinted by Courtesy of the American Petroleum Institute.

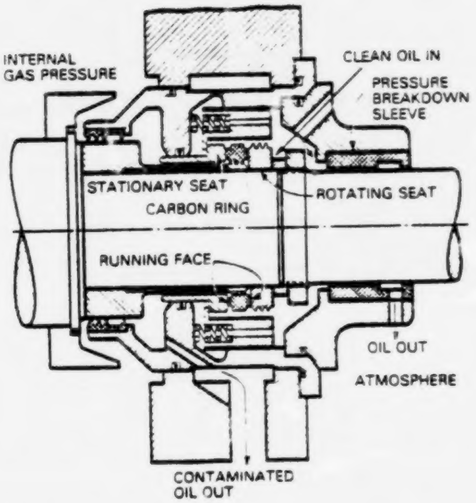
INTERNAL GAS PRESSURE
CLEAN OIL IN
PRESSURE BREAKDOWN SLEEVE
STATIONARY SEAT
CARBON RING
ROTATING SEAT
RUNNING FACE
OIL OUT
ATMOSPHERE
CONTAMINATED OIL OUT

Figure 3-9. Mechanical contact compressor seal.*

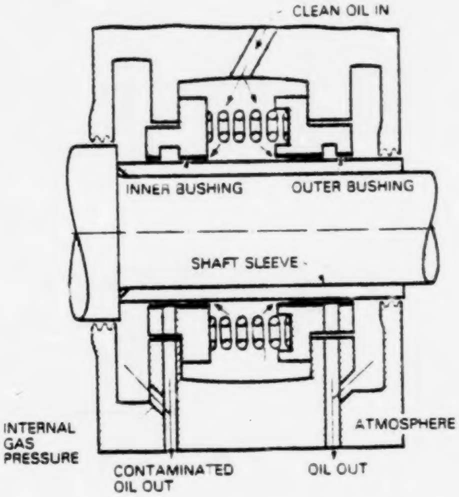
CLEAN OIL IN
INNER BUSHING
OUTER BUSHING
SHAFT SLEEVE
INTERNAL GAS PRESSURE
ATMOSPHERE
CONTAMINATED OIL OUT
OIL OUT

Figure 3-10. Liquid film compressor seal.*

*American Petroleum Institute. Centrifugal Compressors for Refinery Service, API Standard 617, 4th ed., pp. 8-9. Reprinted by Courtesy of the American Petroleum Institute.

When the circulating oil is returned to the oil reservoir, process gas can be released to the atmosphere.[16] To eliminate release of VOC emissions from the seal oil system, the reservoir can be vented to a control device.

3.2.2.3 Process Valves. One of the most common pieces of equipment in organic chemical plants is the valve. The types of valves commonly used are control, globe, gate, plug, ball, relief, and check valves. All except the relief valve (to be discussed further below) and check valve are activated by a valve stem, which may have either a rotational or linear motion, depending on the specific design. This stem requires a seal to isolate the process fluid inside the valve from the atmosphere as illustrated by the diagram of a gate valve in Figure 3-11. The possibility of a leak through this seal makes it a potential source of fugitive emissions. Since a check valve has no stem or subsequent packing gland, it is not considered to be a potential source of fugitive emissions.

Sealing of the stem to prevent leakage can be achieved by packing inside a packing gland or O-ring seals. Valves that require the stem to move in and out with or without rotation must utilize a packing gland. Conventional packing glands are suited for a wide variety of packing material; the most common are various types of braided asbestos that contain lubricants. Other packing materials include graphite, graphite-impregnated fibers, and tetrafluorethylene; the packing material used depends on the valve application and configuration.[17] These conventional packing glands can be used over a wide range of operating temperatures. At high pressures these glands must be quite tight to attain a good seal.[18]

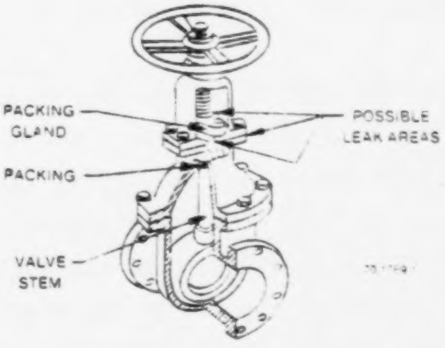

Figure 3-11. Diagram of a gate valve.[19]

Elastomeric O-rings are also used for sealing process valves. These O-rings provide good sealing but are not suitable where there is sliding motion through the packing gland. Those seals are rarely used in high pressure service and operating temperatures are limited by the seal material.[20]

Bellows seals are more effective for preventing process fluid leaks than the conventional packing gland or any other gland-seal arrangement.[21] This type of seal incorporates a formed metal bellows that makes a barrier between the disc and body bonnet joint. An example of this seal is presented in Figure 3-12. The bellows is the weak point of the system and service life can be quite variable. Consequently, this type of seal is normally backed up with a conventional packing gland and is often fitted with a leak detector in case of failure.[22]

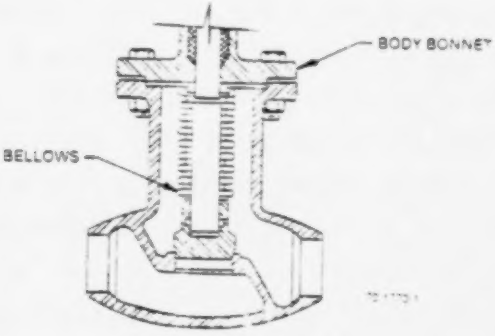

Figure 3-12. Example of bellows seals.[23]

A diaphragm may be used to isolate the working parts of the valve and the environment from the process liquid. Two types of valves which utilize diaphragms are illustrated in Figures 3-11(a) and (b). As Figure 3-11(b) shows, the diaphragm may also be used to control the flow of the process fluid. In this design, a compressor component pushes the diaphragm toward the valve bottom, throttling the flow. The diaphragm and compressor are connected in a manner so that it is impossible for them to be separated under normal working conditions. When the diaphragm reaches the valve bottom, it seats firmly against the bottom, forming a leak-proof seal. This configuration is recommended for fluids containing solid particles and for medium-pressure service. Depending on the diaphragm material, this type of valve can be used at temperatures up to 205°C and in severe acid solutions. If failure of the seal occurs, a valve employing a diaphragm seal can become a source of fugitive emissions.[24]

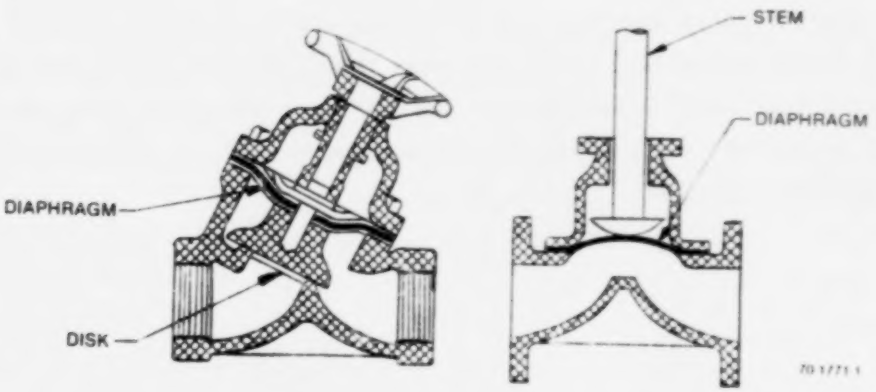

Figure 3-13. Diagrams of valves with diaphragm seals.[25]

3.2.2.4 Pressure Relief Devices. Engineering codes require that pressure-relieving devices or systems be used in applications where the process pressure may exceed the maximum allowable working pressure of the vessel. The most common type of pressure-relieving device used in the SOCMI is the pressure relief valve (Figure 3-14). Typically, relief valves are spring-loaded and designed to open when the process pressure exceeds a set pressure, allowing the release of vapors or liquids until the system pressure is reduced to its normal operating level. When the normal pressure is re-attained, the valve reseats, and a seal is again formed.[26] The seal is a disk on a seat, and the possibility of a leak through this seal makes the pressure relief valve a potential source of VOC fugitive emissions. Two potential causes of leakage from relief valves are: "simmering or popping", a condition due to the system pressure being close to the set pressure of the valve, and improper reseating of the valve after a relieving operation.[27]

Rupture disks are also common in the SOCMI. These disks are made of a material that ruptures when a set pressure is exceeded, thus allowing the system to depressurize. The advantage of a rupture disk is that the disk seals tightly and does not allow any VOC's to escape from the system under normal operation. However, when the disk does rupture, the system depressurizes until atmospheric conditions are obtained; this could result in an excessive loss of product or correspondingly an excessive release of fugitive emissions.

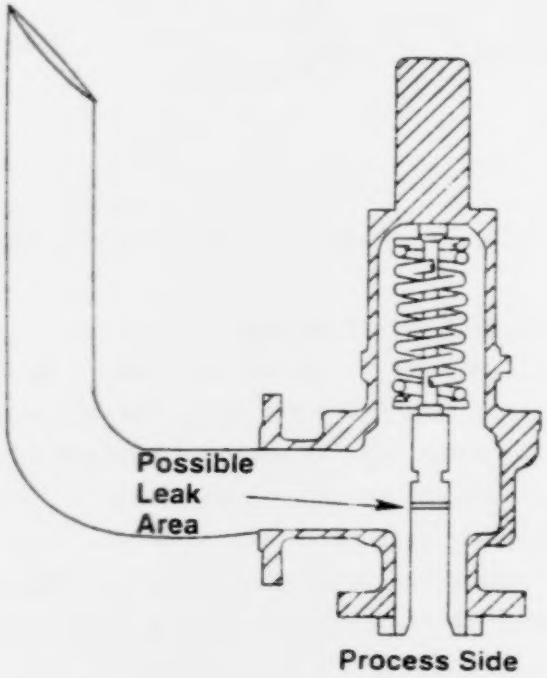

Figure 3-14. Diagram of a spring-loaded relief valve.

3.2.2.5 Cooling Towers. Cooling towers are found in most SOCMI plants. The purpose of these towers is to cool the plant's process cooling waters which have been heated while removing heat from various process equipment (reactors, condensers, heat exchangers). This cooling process is achieved by evaporation when the process cooling water and air are contacted. Under normal operating conditions, a cooling tower would not be considered a fugitive emission source. However, if a leak occurs in the process equipment and if this equipment is operating at a pressure greater than that of the cooling water, organic chemicals can leak into the water. When the process water is recirculated to the cooling tower, these chemicals can be released to the atmosphere.[28]

3.2.2.6 Agitators. Agitators are commonly used in the SOCMI to stir or blend chemicals. Like pumps and compressors, agitators may leak organic chemicals at the point where the shaft penetrates the casing. Consequently, seals are required to minimize fugitive emissions from agitators. Four seal arrangements are commonly used with agitators; they include: compression packing (packed seal), mechanical seals, hydraulic seals, and lip seals.[29] Packed seals for agitators are very similar in design and application to the packed seals for pumps (Section 3.2.2.1).

Although mechanical seals are more costly than the other three seal arrangements, they offer a greatly reduced leakage rate to offset their higher cost. The maintenance frequency of mechanical seals is, also, one-half to one-fourth that of packed seals.[30] In fact, at pressures greater than 1140 kPa (150 psig), the leakage rate and maintenance frequency are so superior that the use of packed seals on agitators is rare.[31] As with packed seals, the mechanical seals for agitators are similar to the design and application of mechanical seals for pumps (Section 3.2.2.1).

The hydraulic seal (Figure 3-15) is the simplest and least used agitator shaft-seal. In this type of seal, an annular cup attached to the process vessel contains a liquid that is in contact with an inverted cup attached to the rotating agitator shaft. The primary advantage of this seal is that it is a non-contact seal. However, this seal is limited to low temperatures and pressures and can only handle very small pressure fluctuations. Organic chemicals may contaminate the seal liquid and then be released into the atmosphere as fugitive emissions.[32]

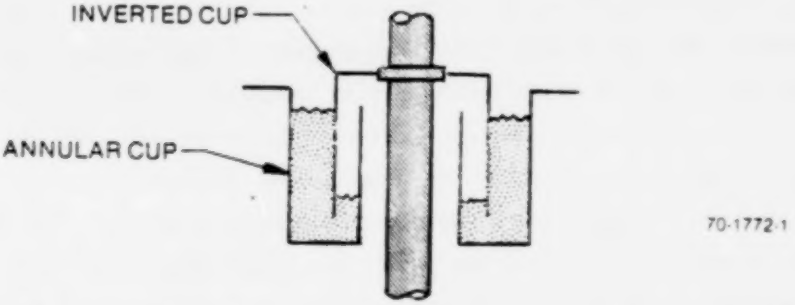

Figure 3-15. Diagram of hydraulic seal for agitators.[33]

A lip seal (Figure 3-16) can be used on a top-entering agitator as a dust or vapor seal. The sealing element is a spring-loaded elastomer. Lip seals are relatively inexpensive and easy to install. Once the seal has been installed the agitator shaft rotates in continuous contact with the lip seal. Pressure limits of the seal are 2 to 3 psi because it operates without lubrication. Operating temperatures are limited by the characteristics of the elastomer. Fugitive VOC emissions could be released through this seal when this seal wears excessively or the operating pressure surpasses the pressure limits of the seal.[34]

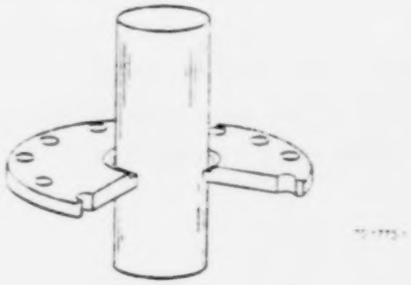

Figure 3-16. Diagram of agitator lip seal.[35]

3.2.2.7 Open-Ended Valves or Lines. Some valves are installed in a system so that they function with the downstream line open to the atmosphere. Examples are purge valves, drain valves, and vent valves. A faulty valve seat, or incompletely closed valve would result in leakage through the valve and fugitive VOC emissions to the atmosphere.

3.2.2.8 Sampling Connections. The operation of a process unit is checked periodically by routine analyses of feedstocks and products. To obtain representative samples for these analyses, sampling lines must first be purged prior to sampling. The purged liquid or vapor is sometimes drained onto the ground or into a sewer drain, where it can evaporate and release VOC emissions to the atmosphere.

3.2.2.9 Flanges. Flanges are bolted, gasket-sealed junctions used wherever pipe or other equipment such as vessels, pumps, valves, and heat exchangers may require isolation or removal. Normally, flanges are employed for pipe diameters of 50 mm or greater and are classified by pressure and face type.

Flanges may become fugitive emission sources when leakage occurs due to improperly chosen gaskets or a poorly assembled flange. The primary cause of flange leakage is due to thermal stress that piping or flanges in some services undergo; this results in the deformation of the seal between the flange faces.[36]

3.3 BASELINE CONTROL

There are presently no federal regulations that specifically reduce emissions from synthetic organic chemical manufacturing plants. However, some fugitive emission reduction is achieved by operating practices currently followed by industry and applicable state or local regulations. Because these practices and regulations only "incidentally" control fugitive emissions, they are considered, in this study, to be the baseline control level. The procedures, specific control techniques, and regulations that make up the baseline control level are discussed below.

Fugitive emissions occurring under the baseline control level are subsequently considered in this report to be uncontrolled emissions. Data characterizing the uncontrolled levels of fugitive emissions in the SOCMI are presently unavailable. However, data of this type have been obtained for the refining industry. These data are presented in Table 3-1. Because the operation of the various process equipment in the SOCMI is not expected to differ greatly from the operation of the same equipment in the refining industry, it is felt that the refinery fugitive emission data can be used to approximate the levels of fugitive emissions in SOCMI. Test data in Appendix C.1 indicate that this engineering judgement is reasonable. These data show that leak rates and leak frequencies within SOCMI and petroleum refineries are similar.

3.3.1 Industrial Practices

The organic chemical industry has been primarily interested in leaks that are large enough to be physically evident (leaks that can be seen, heard, or smelled); such leaks are termed "easily detectable leaks" and are normally repaired to minimize the loss of product. Fugitive emissions, as they are considered in this report, have considerably smaller emission rates than "easily detectable leaks." In the past, SOCMI generally has not monitored equipment for fugitive emissions nor repaired equipment on the basis of reducing the level of fugitive emissions. Processes which have emitted toxic or hazardous compounds have been exceptions to this rule.

While SOCMI has been concerned primarily with easily detectable leaks, certain equipment and procedures used in many organic chemical plants may help to reduce fugitive VOC emissions. For instance, some plants cap-off or use double block valves on the end of process lines. Either of these procedures will reduce fugitive emissions. In some plants relief valves are checked to see if the valve has reseated properly after relieving.[27] As previously mentioned, an improperly seated relief valve may allow fugitive VOC emissions to occur. Rupture discs, which are commonly used in the SOCMI, also prevent fugitive VOC emissions. Some organic chemical plants employ closed-loop sampling which help to reduce fugitive emissions.

TABLE 3-1. UNCONTROLLED FUGITIVE EMISSION FACTORS IN THE SYNTHETIC ORGANIC CHEMICAL MANUFACTURING INDUSTRY (SOCMI)

Fugitive emission source	Uncontrolled emission factor,[a] kg/hr
Pumps	
Light liquids[b]	
With packed seals	0.12
With single mechanical seals	0.12
With double mechanical seals	0.12[c]
With no seals	0.0
Heavy Liquids[d]	
With packed seals	0.020
With single mechanical seals	0.020
With double mechanical seals	0.020[c]
With no seals	0.0
Valves (in-line)	
Gas	0.021
Light liquid[b]	0.010
Heavy liquid[d]	0.0003
Safety/relief valves	
Gas	0.16
Light liquid[b]	0.006
Heavy liquid[d]	0.009
Open-ended valves	
Gas	0.025
Light liquid[b]	0.014
Heavy liquid[d]	0.003
Flanges	0.0003
Sampling connections	0.015
Compressors	0.44
Cooling towers	13.6-1107[e]
Agitators	NA[f]

---

[a] These uncontrolled emission levels are based upon the refinery data presented in reference 38.

[b] Light liquid is defined as a fluid with vapor pressure greater than 0.3 kPa at 20°C. This vapor pressure represents the split between kerosene and naphtha and is based on data presented in reference 39. The average vapor pressure of liquids falling between these two components is approximately 0.04 psi at 68°F.

[c] Assumes the inner seal leaks at the same rate as single seal and that the VOC is emitted from the seal oil degassing vent.

[d] Heavy liquid is defined as a fluid with vapor pressure less than 0.3 kPa at 20°C. This vapor pressure represents the split between kerosene and naphtha and is based on data presented in reference 40. The average vapor pressure of liquids falling between these two components is approximately 0.04 psi at 68°F.

[e] These levels are based on cooling tower circulation rates that range from 0.05-3.66 m^3/sec (714-58,000 GPM). Ref. 41.

[f] NA = no data available.

The flaring of vapors vented from various vessels or equipment is another technique which is used by some plants (particularly those producing toxic or hazardous chemicals) to reduce fugitive emissions.

3.3.2 Existing Regulations

There are, presently, two types of regulations that impact fugitive VOC emissions from organic chemical plants. The first type is to regulate industrial operating practices on the basis of worker health and safety. Because some aspects of these regulations deal with worker exposure to process emissions, they may have some impact on fugitive VOC emissions. The second type of regulations is regulations that were specifically developed to limit fugitive emissions.

3.3.2.1 Health and Safety Regulations. Several regulations have been established under the direction of the Occupational Safety and Health Administration and National Institute for Occupational Safety and Health to limit worker exposure to chemical substances. Protecting the workers may be accomplished by either limiting the level of emissions or by providing workers with protection from the emissions. In this way, regulations may result in a reduction in the levels of fugitive VOC emissions.

In the vinyl chloride monomer and benzene industries, safety and health regulations are designed to limit the ambient VOC levels to which workers may be exposed. Since these standards do not stipulate how the allowable ambient levels should be achieved, workers can be protected from high ambient VOC levels by: 1) a reduction in the fugitive VOC emissions or 2) the use of special equipment (such as personal respirators) to isolate the worker from the emissions. This example illustrates that the present health and safety regulations do not mandate a reduction in fugitive VOC emissions, and any reduction in fugitive emissions resulting from these regulations can be considered to be "incidental". By contrast, fugitive emission regulations do require the fugitive emissions to be reduced.

3.3.2.2 Fugitive Emissions Regulations. Currently, there are no federal fugitive emission regulations for the SOCMI. However, California has established such regulations, and organic chemical plants in this state must comply with the appropriate regulations.

California presently requires open-ended process lines to be capped-off in order to minimize fugitive VOC emissions. This state also requires relief valves to be vented to a flare system, monitored and maintained, or a rupture disk to be used. In addition to these regulations, the South Coast Air Quality Management District requires organic chemical plants to vent fugitive emissions from compressor seals to a fired-heater or flare system. The South Coast and Bay Area AQMD also require periodic inspection of valves in the chemical and refining industries.

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4. EMISSION CONTROL TECHNIQUES

Sources of fugitive VOC emissions from SOCMI plants were identified in Chapter 3 of this document. The potential emission control techniques that can be applied to SOCMI fugitive emission sources are discussed in this chapter. The applicability and estimated control effectiveness of each technique are also presented. The quantitative control effectiveness for many of the control techniques is not known. Qualitative discussions of effectiveness and references to technology transfer from similar industries are presented wherever applicable.

4.1 LEAK DETECTION AND REPAIR METHODS

Leak detection and repair methods can be applied in order to reduce fugitive emissions from any source. Leak detection methods are used to identify equipment components that are emitting significant amounts of VOC. Emissions from leaking sources may be reduced by three general methods: repair, modification, or replacement of the source.

4.1.1 Leak Detection Methods

Leak detection methods include individual component surveys, area (walk-through) surveys, and fixed point monitors. The first method (individual component surveys) is also a part of the other methods.

4.1.1.1 Individual Component Survey. Each fugitive emission source (pump, valve, compressor, etc.) is checked for VOC leakage in an individual component survey. The source may be checked for leakage by visual, audible, olfactory, soap bubble, or instrument techniques. Visual methods are good for locating liquid leaks, especially pump seal failures. Observation of a visible leak does not necessarily indicate VOC emissions, since the leak may be composed of non-VOC compounds. High pressure leaks may be detected by hearing the escaping vapors, and leaks of odorous materials may be detected by smelling the odor. Current industry practices include leak detection by visual, audible, and olfactory methods. However, in many instances, even very large VOC leaks are not detected by these methods.

Spraying soap on equipment components is another individual survey method. If the soap solution forms bubbles or is blown away, a leak from the component is indicated. A disadvantage of this method is that it does not distinguish leaks of non-VOC compounds from VOC leaks. Consequently, air or steam leaks would produce the same observed effect as VOC leaks. This method is only semiquantitative since it requires that the observer subjectively determine the rate of leakage based on behavior of the soap bubbles. This method is limited to "cool" sources, since temperatures above 100°C would cause the water in the soap solution to boil away. This method is also not suited for moving shafts on pumps or compressors, since the motion of the shaft may interfere with the motion of the bubbles caused by a leak.

Portable hydrocarbon detection instruments are the best method for identifying leaks of VOC from equipment components. The instrument is used to sample and analyze the air in close proximity to the potential leak surface by traversing the sampling probe tip over the entire area where leaks may occur. This sampling traverse is called "monitoring" in subsequent descriptions. The hydrocarbon concentration of the sampled air is displayed on the instrument meter. The performance criteria for monitoring instruments and a description of instrument survey methods are included in Appendix D. The hydrocarbon concentration observed during monitoring of a component is proportional to the VOC emission rate from the component. Data from petroleum refineries have been used to develop relationships between monitoring concentration and mass emission rates. The hydrocarbon concentration which indicates that a component needs maintenance must be chosen. Components which have indicated concentrations higher than this "action level" are marked for repair. Data from petroleum refineries indicate that large variations in mass emission rate may occur over short time periods for an individual equipment component. More frequent monitoring intervals tend to reduce the chance of missing "large leaks" because of their variable leak rates.

4.1.1.2 Area Survey. An area survey (also known as a walk-through survey) requires the use of a portable hydrocarbon detector and a strip chart recorder. The procedure involves carrying the instrument within one meter of the upwind and downwind sides of process equipment and associated fugitive emission sources. An increase in observed concentration indicates leaking fugitive emission sources. The instrument is then used for an individual component survey in the suspected leak area. The efficiency of this method for locating leaks is not well established. It has been estimated that the walk-through survey combined with selected individual surveys will detect about 50 percent of the number of leaks identified in a complete individual survey.[1] The time and labor requirements for the walk-through are much lower. This method will not detect leaks from sources such as elevated valves or relief valves. Leaks from adjacent units and adverse meteorological conditions can affect the results of the walk-through survey. Consequently, the walk-through survey is best for locating only large leaks with a small resource expenditure.

4.1.1.3 Fixed Point Monitors. This method consists of placing several automatic hydrocarbon sampling and analysis instruments at various locations in the process unit. The instruments may sample the ambient air intermittently or continuously. Elevated hydrocarbon concentrations indicate a leaking component. As in the walk-through method, an individual component survey is required to identify the specific leaking component in the area. For this method, the portable hydrocarbon detector is also required. Leaks from adjacent units and meteorological conditions may affect the results obtained. The efficiency of this method is not well established, but it has been estimated that 33 percent of the number of leaks identified by a complete individual component survey could be located by fixed-point monitors.[2] Fixed-point monitors are more expensive, multiple units may be required, and the portable instrument is also required to locate the specific leaking component.

calibration and maintenance costs may be higher. Fixed-point monitors have been used to detect emissions of hazardous or toxic substances (such as vinyl chloride) as well as potentially explosive conditions. Fixed-point monitors have an advantage in these cases, since a particular compound can be selected as the sampling criterion.

4.1.2 Repair Methods

The following descriptions of repair methods include only those features of each fugitive emission source (pump, valve, etc.) which need to be considered in assessing the applicability and effectiveness of each method. They are not intended to be complete repair procedures. The effectiveness of repairs in reducing fugitive emissions has not been well documented; however, data for valve repairs have been collected in various petroleum refineries. In many cases, perfect repair will not be achieved, but whenever repairs are performed, the portable hydrocarbon detector should be used to identify the lowest achievable emission rate.

4.1.2.1 Pumps. Many pumps have spares which can be operated while the leaking pump is being repaired. Leaks from packed seals may be reduced by tightening the packing gland. At some point, the packing may deteriorate to the point where further tightening would have no effect or possibly even increase fugitive emissions from the seal. The packing can be replaced with the pump out of service. When mechanical seals are utilized, the pump must be dismantled so the leaking seal can be repaired or replaced. Dismantling pumps, if the seal leak is small, may result in spillage of some process fluid and evaporative emissions of VOC. These temporary emissions may be greater than the continued leak from the seal.

4.1.2.2 Compressors. Leaks from packed seals may be reduced by the same repair procedure that was described for pumps. Other types of seals require that the compressor be out of service for repair. Since most compressors do not have spares, repair or replacement of the seal would require a shutdown of the process. If the leak is small, temporary emissions resulting from a shutdown may be greater than the emissions from the leaking seal.

4.1.2.3 Relief Valves. In general, relief valves which leak must be removed in order to repair the leak. In some cases of improper reseating, manual release of the valve may improve the seat seal. In order to remove the relief valve without shutting down the process, a block valve may be required upstream of the relief valve. A spare relief valve should be attached while the faulty valve is repaired and tested. After a relief valve has been repaired and replaced, there is no guarantee that the next over-pressure relief will not result in another leak.

4.1.2.4 Valves. Most valves have a packing gland which can be tightened while in service. Although this procedure should decrease the emissions from the valve, in some cases it may actually increase the emission rate if the packing is old and brittle or has been overtightened. Plug type valves can be lubricated with grease to reduce emissions around the plug. Some types of valves have no means of in-service repair and must be isolated from the process and removed for repair or replacement. Other valves, such as control valves, may be excluded from in-service repair by operating or safety procedures. In many cases, valves cannot be isolated from the process for removal. Most control valves have a manual bypass loop which allows them to be isolated and removed. Most block valves cannot be isolated easily although temporary changes in process operation may allow isolation in some cases. If a process unit must be shut down in order to isolate a leaking valve, the emissions resulting from the shutdown will probably be greater than the emissions from the valve if allowed to leak until the next process change which permits isolation for repair.

Depending on site specific factors, it may be possible to repair process valves by injection of a sealing fluid into the source. This type of repair may affect the operability of the valve so that replacement of the source might be necessary within a short time after its repair. Injection of sealing fluid has been successfully used to repair leaks from valves in petroleum refineries in California.[3]

4.1.2.5 Flanges. In some cases, leaks from flanges can be reduced by replacing the flange gaskets. Most flanges cannot be isolated to permit replacement of the gasket. Data from petroleum refineries show that flanges emit very small amounts of VOC.[4]

4.1.3 Control Effectiveness of Leak Detection and Repair Methods

The instrument survey of individual components is the only type of leak detection method for which control effectiveness has been quantified. The following estimations of control effectiveness do not pertain to the soap bubble leak detection method, area surveys, or fixed-point monitoring methods.

There are several factors which determine the control effectiveness of individual component surveys; these include

- Action level or leak definition,
- Inspection interval or monitoring frequency,
- Achievable emission reduction of maintenance, and
- Interval between detection and repair of the leak.

Some of these factors can be estimated by using data collected from petroleum refineries.[5]

4.1.3.1 Action Level. The action level is the minimum hydrocarbon concentration observed during monitoring which defines a leaking component which requires repair. The choice of the action level for defining a leak is influenced by a number of important considerations. First, the percent of total mass emissions which can potentially be controlled by the monitoring and repair program can be affected by varying the leak definition, or action level. Table 4-1 gives the percent of total mass emissions affected by various action levels for a number of equipment types. The data in this table, indicate that, in general, a low action level results in larger potential emission reductions. However, the choice of an appropriate leak definition is most importantly limited by the ability to repair leaking components. Test data indicate that about 90 percent of valve leaks with initial screening values equal to or greater than 10,000 ppmv can be successfully repaired (see Appendix C). Similar data indicate that attempted repair of valve leaks with initial screening

TABLE 4-1. FRACTION OF TOTAL MASS EMISSIONS FROM VARIOUS SOURCE TYPES THAT WOULD BE AFFECTED BY DIFFERENT ACTION LEVELS[a]

Action level[b] (ppmv)	Fraction of mass emissions (as %)			
	100,000	50,000	10,000	1,000
Source type				
Pump seals				
Light liquid service	56	68	87	97
Heavy liquid service	0	0	21	66
In-line valves				
Vapor service	85	92	98	99
Light liquid service	49	62	84	96
Heavy liquid service	0	0	0	23
Safety/relief valves	20	33	69	92
Compressor seals	28	48	84	98
Flanges	0	0	0	48

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[a] These data show the fraction of the total emissions from a given source type that is attributable to sources with leaks above the various action levels.[6]

[b] Level of emission at which repair of the source is required.

values of less than 10,000 ppmv can increase instead of decrease emissions from these valves. From these data it is concluded that repairing leaks with screening values in the 1,000-10,000 ppmv range may not result in a net reduction in mass emissions.[7] The nature of repair techniques for pipeline valves, for instance, are such that to repair leaks below a certain level by tightening valve packing may actually result in an increase in emissions. In practice, valve packing material becomes hard and brittle after extended use. As the packing loses its resiliency, the valve packing gland must be tightened to prevent loss of product to the atmosphere. Excessive tightening, however, may cause cracks in the packing, thereby increasing the leak rate. Unbalanced tightening of the packing gland may also cause the packing material to be positioned improperly in the valve and allow leakage. Valves which are not often used can build up a "static" seal of paint or hardened lubricant which could be broken by tightening the packing gland. Therefore, it may be important not to cause small leaks to become large leaks by requiring tightening of valves to meet a very low leak repair action level.

4.1.3.2 Inspection Interval. A monitoring plan may include annual, quarterly, monthly, or even weekly inspections. The length of time between inspections should depend on the expected occurrence and recurrence of leaks after a piece of equipment has been checked or repaired. This interval can be related to the type of equipment and service conditions, and different intervals can be specified for different pieces of equipment after appropriate equipment histories have been developed. In the refinery VOC leak Control Techniques Guideline (CTG) document,[8] the recommended monitoring intervals are: annual--pump seals, pipeline valves in liquid service, and process drains; quarterly--compressor seals, pipeline valves in gas service, and pressure relief valves in gas service; weekly--visual inspection of pump seals; and no individual monitoring--pipeline flanges and other connections, and pressure relief valves in liquid service. The choice of the interval affects the emission reduction achievable since more frequent inspection will result in leaking sources being found and fixed sooner. In order to evaluate the effectiveness of different inspection intervals, it is necessary to estimate the rate at which new leaks will occur and repaired leaks will recur. The estimates which have been used to evaluate yearly, quarterly, and monthly inspections are shown in Table 4-2.

4.1.3.3 Allowable Interval Before Repair. If a leak is detected, the equipment should be repaired within a certain time period. The allowable repair time should reflect an interest in eliminating a source of VOC emissions but should also allow the plant operator sufficient time to obtain necessary repair parts and maintain some degree of flexibility in overall plant maintenance scheduling. The determination of this allowable repair time will affect emission reductions by influencing the length of time that leaking sources are allowed to continue to emit pollutants. Some of the components with concentrations in excess of the leak definition action level may not be able to be repaired until the next scheduled unit shutdown, e.g., a unit turnaround.

The effects of different allowable repair intervals are shown in Table 4-3. The percentages shown in the table are the percent of emissions from the component which would be affected by the repair if all other contributing factors were 100 percent efficient. The emissions which occur between the time the leak is detected and repair is attempted are increased with increasing allowable repair intervals.

4.1.3.4 Achievable Emission Reduction. Repair of leaking components will not always result in complete emission reduction. The repair of components which have initial monitoring levels below 1,000 ppm has not been adequately demonstrated. Repair of those components with low initial leak rates may actually result in an emission rate increase. However, in order to estimate repair effectiveness, it was assumed that emissions could be reduced to a level of 1,000 ppm. The average emission rates of components above 10,000 ppm and at 1,000 ppm are shown in Table 4-4.

4.1.3.5 Development of Controlled Emission Factors. The uncontrolled emission levels for the emission sources that are typically found in the model plants were previously presented in Chapter 3 (Table 3-1). Controlled VOC emission levels can be calculated by a "controlled emission" factor. This factor can be developed for each tvpe of emission source by using the general expression:

TABLE 4-2. ESTIMATED OCCURRENCE AND RECURRENCE RATE OF LEAKS FOR VARIOUS MONITORING INTERVALS

Source type	Estimated percent of sources leaking at above 10,000 ppm initially[a]	Estimated percent of initial leaks which are found leaking at subsequent inspections[b]			Estimated percent of sources which are found leaking at subsequent inspections[c]		
		Annual	Quarterly	Monthly	Annual	Quarterly	Monthly
Pump seals							
Light liquid service	23	20	10	5	4.6	2.3	1.2
Heavy liquid service	2	20	10	5	0.4	0.2	0.1
In-line valves							
Vapor service	10	20	10	5	2.0	1.0	0.5
Light liquid service	12	20	10	5	2.4	1.2	0.6
Heavy liquid service	0	20	10	5	0.0	0.0	0.0
Safety/relief valves	8	20	10	5	1.6	0.8	0.4
Compressor seals	33	20	10	5	6.3	3.3	1.7
Flanges	0	20	10	5	0.0	0.0	0.0

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[a] Approximate fraction of sources having leaks equal to or greater than 10,000 ppm prior to repair.[9]

[b] Approximate fraction of leaking sources that were repaired but found to leak during subsequent inspections. These approximations are based on engineering judgment.

[c] Approximate fraction of sources that were repaired but found to leak during a subsequent inspection. These approximations are the product of the information presented in footnotes a and b.

TABLE 4-3. MAXIMUM POTENTIAL CONTROL EFFICIENCY AS A FUNCTION OF REPAIR INTERVAL ASSUMING 100 PERCENT EFFICIENCY FOR OTHER FACTORS[a]

Allowable repair interval (days)	30	15	5	1
Percent of emissions affected	95.9	97.9	99.3	99.9

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[a] Assumes that efficiencies of all other control factors (action level, achievable emission reduction, monitoring frequency) are 100 percent.

TABLE 4-4. AVERAGE EMISSION RATES FROM SOURCES ABOVE 10,000 PPMV AND AT 1000 PPMV[10]

Source type	(Y) Emission rate from sources above 10,000 ppmv[a] (kg/hr)	(X) Emission rate from sources at 1000 ppmv[b] (kg/hr)	$(\frac{Y - X}{Y})(100)$ Percentage reduction
Pump seals			
Light liquid service	0.45	0.035	92.0
Heavy liquid service	0.21	0.035	83.0
In-line valves			
Vapor service	0.21	0.001	99.5
Light liquid service	0.07	0.004	94.0
Heavy liquid service	0.005	0.004	20.0
Safety/relief valves	1.4	0.035	97.5
Compressor seals	1.1	0.035	97.0
Flanges	0.003	0.002	33.0

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[a] Average emission rate of all sources, within a source type, having screening values above 10,000 ppmv.

[b] Emission rate of all sources, within a source type, having screening values of 1000 ppmv.

Controlled emission factor = Uncontrolled factor - uncontrolled factor x emission reduction efficiency

The reduction efficiency can be developed by the following expression and correction factors:

$$\text{Reduction efficiency} = A \times B \times C \times D$$[11]

Where:

A = Theoretical Maximum Control Efficiency = fraction of total mass emissions for each source type with VOC concentrations greater than the action level (Table 4-1, Figure 4-1).

B = Leak Occurrence and Recurrence Correction Factor = correction factor to account for sources which start to leak between inspections (occurrence); for sources which are found to be leaking, are repaired and start to leak again before the next inspection (recurrence) (Tables 4-2, 4-6); and for known leaks which are not repaired.

C = Non-Instantaneous Repair Correction Factor = correction factor to account for emissions which occur between detection of a leak and subsequent repair; that is, repair is not instantaneous (Table 4-3).

D = Imperfect Repair Correction Factor = correction factor to account for the fact that some sources which are repaired are not reduced to zero emission levels. For computational purposes, all sources which are repaired are assumed to be reduced to a 1000 ppm emission level (Table 4-4).

These correction factors can, in turn, be determined from the following expressions:

$$(1) \quad B = 1 - \frac{\overline{n}_m}{N}$$

$$(2) \quad C = \frac{365 - t}{365}$$

$$(3) \quad D = 1 - \frac{f}{F}$$

Where:

$\bar{n}_m$ = Average number of leaks occurring and recurring over the monitoring interval (including known leaks which were not repaired).

N = Total number of sources at or above the action level (Figure 4-2).

t = Average time before repairs are made (with a 15-day repair limit, 7.5 is the average used).

f = Average emission factor for sources at the average screening value achieved by repair.

F = Average emission factor for all sources at or above the action level.

An example of a control effectiveness calculation is presented in Table 4-5. Support data for this calculation are presented in Tables 4-1, 4-2, 4-3, 4-4, and 4-6, as well as in Figures 4-1 and 4-2.

4.2 EQUIPMENT SPECIFICATIONS

Fugitive emissions may be reduced by using process equipment which is designed to prevent leakage. Equipment specifications for each emission source are described below. Some of the specifications may be applicable to more than one type of source.

4.2.1 Pumps

Fugitive emissions from pumps occur at the junction of a moving shaft and a stationary casing. Equipment specifications that may be implemented for pumps include elimination of this junction, improvement of the seal at the junction, or collection and control of the emissions from the junction.

4.2.1.1 Sealless Pumps. Pumps such as diaphragm type pumps or "canned" pumps do not have a shaft/casing junction and therefore do not leak the pumped fluid in the normal course of operation. However, failure of the diaphragm in a diaphragm pump may result in temporary emissions of VOC. Sealless pumps are used primarily in SOCMI processes where the pumped fluid is hazardous or toxic, and every effort must be made to prevent leaks of the fluid.

TABLE 4-5. EXAMPLE OF CONTROL EFFICIENCY CALCULATION

Assume:

1) A leak detection and repair program to reduce emissions from valves in gas/vapor source.
2) Action level = 10,000 ppm.
3) Average screening value after directed repair = 1,000 ppm.
4) Leak detection monitoring interval = 3 months.
5) Allowable repair interval = 15 days.
6) Number of valves having new or recurring leaks between repair intervals, $n_m = 0.2N$ (see Table 4-6).

Calculations:

A = 0.98 (from Figure 4-1 for a screening value of 10,000 ppmv)

B = 0.9 (from Table 4-6)

C = 0.979 (from Table 4-3 for 15-day interval)

where:

$$F = \frac{A(\text{Avg. uncontrolled emission factor})^{a}}{\text{Fraction of sources screening} \geq 10{,}000\ \text{ppm}^{b}}$$

$$= (0.98)(0.021\ \text{kg/hr})/0.10 = 0.206\ \text{kg/hr}$$

$$f = \text{Emission factor at 1000 ppm}^{c}$$

$$= 0.001\ \text{kg/hr}$$

$$\text{and } D = (1 - \frac{0.001}{0.206}) = 0.995$$

Overall percentage reduction = A x B x C x D

= (0.98) x (0.9) x (0.979) x (0.995)

= 86 Percent

Therefore:

Control effectiveness factor = 0.021 kg/hr - (0.86)(0.021 kg/hr)

= 0.003 kg/hr

---

[a] Reference 12.

[b] From Figure 4-2.

[c] Reference 13.

TABLE 4-6. IMPACT OF MONITORING INTERVAL ON CORRECTION FACTOR ACCOUNTING FOR LEAK OCCURRENCE/RECURRENCE (FOR EXAMPLE CALCULATION)

Monitoring interval	n_m[a]	$\bar{n}_m$[b]	B[c]
1 month	0.1N[d]	0.05N	0.95
3 months	0.2N	0.1N	0.90
1 year	0.4N	0.2N	0.80

[a] n_m = Total number of leaks which occur, recur, and remain between monitoring intervals.

[b] $\bar{n}_m$ = Average number of leaks over the monitoring interval.

[c] B = Correction factor accounting for leak occurrence/recurrence.

[d] N = Total number of sources at or above the action level.

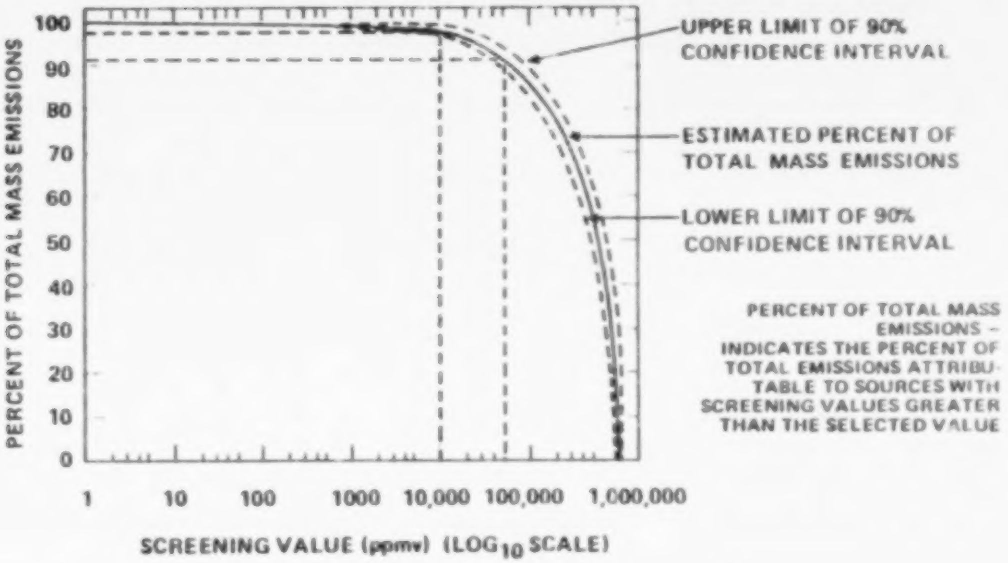

Figure 4-1. Cumulative distribution of total emissions by screening values - valves - gas/vapor streams.[14]

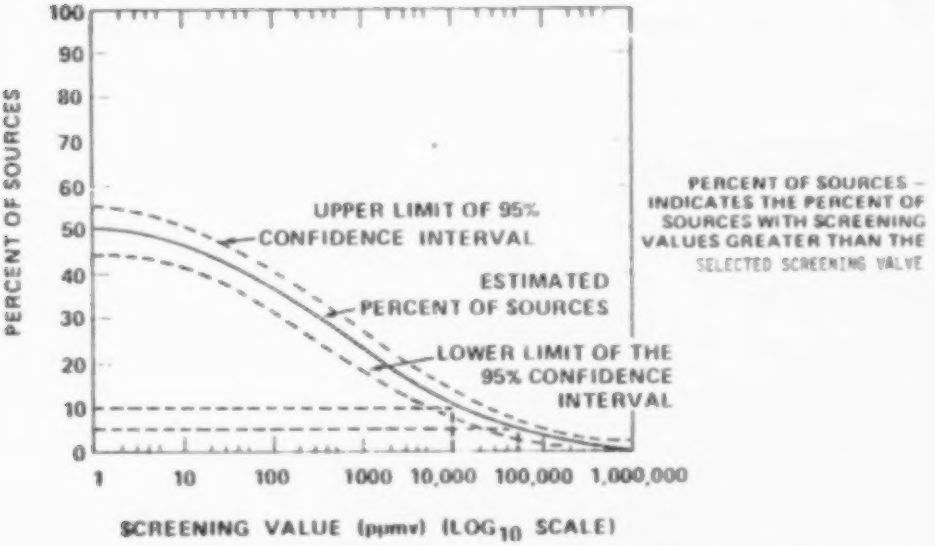

Figure 4-2. Cumulative distribution of sources by screening values - valves - gas/vapor streams.[15]

4.2.1.2 Dual Mechanical Seals. Dual mechanical seals consist of two mechanical sealing elements usually arranged in a back-to-back or tandem configuration. In both configurations a barrier fluid circulates between the seals. In the back-to-back arrangement the barrier fluid system is at a higher pressure than the pressure in the seal area. Therefore, any leakage of barrier fluid would be across the inner seal into the product and across the outer seal to the environment. In the tandem configuration the barrier fluid may be at a lower pressure than that of the seal area. If the pressure in the barrier fluid system is lower, any leakage of product would occur across the inner seal into the barrier fluid. Any leaks into the barrier fluid may be dissolved or suspended in the barrier fluid, and subsequent degassing of the barrier fluid may result in emissions of VOC. Therefore, barrier fluid degassing vents would have to be controlled to provide maximum control effectiveness of dual mechanical seals.

The barrier fluid system may be a circulating system or it may rely on convection to circulate fluid within the system. While the barrier fluid's main function is to keep the pumped fluid away from the environment, it can serve other functions as well. A barrier fluid can provide temperature control in the stuffing box. It can also protect the pump seals from the atmosphere, as in the case of pumping easily oxidizeable materials which form abrasive oxides or polymers upon exposure to air. A wide variety of fluids can be used as barrier fluids. Some of the more common ones which have been used are water (or steam), glycols, methanol, oil, and heat transfer fluid. In cases in which product contamination cannot be tolerated, it may also be possible to use clean product, a product additive, or a product diluent.

Emissions of VOC from degassing vents can be controlled by a closed vent system which consists of piping and, if necessary, flow inducing devices to transport the degassing emissions to a control device such as a process heater, or vapor recovery system. Control effectiveness of a dual mechanical seal and closed vent system is dependent on the effectiveness of the control device used and the frequency of seal failure. Failure of both the inner and outer seals can result in relatively large VOC emissions at the seal area of the pump. Pressure monitoring of the barrier fluid may be used in order to detect failure of the seals.[16] In addition, visual inspection of the seal area also can be effective for detecting failure of the outer seals. Upon seal failure, the leaking pump would have to be shut down for repair.

Dual mechanical seals are used in many SOCMI process applications; however, there are some conditions that preclude the use of dual mechanical seals. Their maximum service temperature is usually limited to less than 260°C, and mechanical seals cannot always be used successfully on pumps with reciprocating shaft motion.

4.2.1.3 Closed Vent Systems. The system described above for controlling degassing vent emissions could also be applied to control emissions from the seal area of pumps. This application would require the use of some type of flow inducing device to transport the emissions from the seal area to the control device. The seal area would be enclosed in order to collect the emissions and a vacuum eductor or a compressor could be used to remove vapors from the seal area. However, normal pump operating practices may require frequent visual inspection or mechanical adjustments in the seal area. This would not be possible with a closed vent system at the seal area. A potential problem with this approach is that explosive mixtures may be created by enclosing the pump seal area, and therefore safety and operating practices may limit the use of closed vent systems for pump seal areas.

4.2.1.4 Control Device. Several types of controls could be used to dispose of VOC emissions trapped in the pump seal barrier fluid. Incineration, carbon adsorption, and condensation are three control methods which might typically be applied. Control efficiencies of the three methods are dependent on specific operating characteristics and types of VOC. However, incineration can achieve better than 95 percent efficiency.[17] Temperature and residence time affect the VOC destruction efficiency. A temperature of 1400°F and a residence time of 0.5 seconds residence time results in $\geq$ 90 percent efficiency. A temperature of 1500°F combined with a residence time of 0.5 seconds gives $\geq$98 percent VOC destruction.[18]

Carbon adsorption systems can achieve 95-99 percent control efficiency through proper design and operation.[19] Condensation systems can achieve ≥90 percent VOC capture.[20]

Flares, while they are commonly used in chemical plants, would not be as applicable to these small vent streams as they are to larger streams. Flare efficiency can vary from 60 to 99 percent[21] depending on how closely the design specifications match the flow characteristics of the VOC conveyed to the flare.

4.2.2 Compressors

Fugitive emissions from compressors occur at the junction of a moving shaft and a stationary casing. Emission reductions from this source type may be achieved by improving the seal at the junction, or collecting and controlling the emissions from the junction.

4.2.2.1 Mechanical Contact. Mechanical contact seals for compressors are similar to the mechanical seals described for pump applications. However, compressors in some services cannot be fitted with mechanical contact seals. Existing compressors may have mechanical contact seals equipped with seal oil flush systems. Seal oil reservoir degassing vents must be controlled with closed vent systems as described for pumps. Sometimes a buffer or barrier gas may be used to form a buffer between the compressed gas and the atmosphere. This system requires a clean external gas supply which is compatible with the gas being compressed. Contaminated barrier gas must be disposed of properly. The control efficiency for mechanical contact seals is dependent on the control device efficiency and the frequency of seal failures.

4.2.2.2 Closed Vent Systems. The seal area of a compressor may be enclosed, and the VOC emissions routed to a control device through a closed vent system. However, flow inducing devices may be required to transport vapors to the control device. Although the formation of explosive mixtures in the enclosed seal area may prohibit application of this equipment modification to some process units, closed vent systems have been applied to compressor seal areas in petroleum refineries.

4.2.2.3 Control Device. Several types of controls could be used to dispose of VOC emissions collected from compressor seal areas. Incineration, carbon adsorption, and condensation are three control methods which might typically be applied. Control efficiencies of the three methods are dependent on specific operating characteristics and types of VOC. However, incineration can achieve better than 95 percent efficiency.[22] Temperature and residence time affect the VOC destruction efficiency. A temperature of 1400°F and a residence time of 0.5 seconds residence time results in 90 percent efficiency. A temperature of 1500°F combined with a residence of 0.5 seconds gives $\geq$98 percent VOC destruction.[23]

Carbon adsorption systems can achieve 95-99 percent control efficiency through proper design and operation.[24] Condensation systems can achieve $\geq$90 percent VOC capture.[25]

Flares, while they are commonly used in chemical plants, would not be as applicable to these small vent streams as they are to larger streams. Flare efficiency can vary from 60 to 99 percent[26] depending on how closely the design specifications match the flow characteristics of the VOC conveyed to the flare.

4.2.3 Pressure Relief Devices

Pressure relief devices include rupture disks and safety/relief valves. Fugitive emissions from these devices occur because of improper seating or partial failure of the device. These fugitive emissions do not include emissions which result from normal operation of the devices caused by overpressure of the process or vessel which the device protects. Fugitive emissions from rupture disks may be caused by pinhole leaks in the disk itself caused by corrosion or fatigue. Fugitive emissions from relief valves may be caused by failure of the valve seating surfaces, improper reseating after overpressure relieving, or process operation near the relief valve set pressure which may cause "simmering".

4.2.3.1 Rupture Disks. Although they are also pressure relief devices, rupture disks can be installed upstream of a safety/relief valve in order to prevent fugitive emissions through the relief valve seat. This procedure may require use of a larger size relief valve because of operating codes. The disk/valve combination may also require appropriate piping changes to prevent disk fragments from lodging in and damaging the relief valve when relieving overpressure. A block valve upstream of the rupture disk is also required in order to permit in-service replacement of the disk after overpressuring. If the disk could not be replaced, the first overpressure would result in the relief valve being the same as an uncontrolled relief valve. In some chemical plants, installation of a block valve upstream of a pressure relief device may be a common practice. While it is allowed by ASME codes,[27] it may be forbidden by operating or safety procedures for a particular company. Tandem pressure relief devices with a three-way valve can be used to avoid operation without overpressure protection. Rupture disk/relief valve combinations must have some provision for testing the integrity of the disk. The area between the rupture disk and relief valve must be connected to a pressure indicator, recorder, or alarm. If the process fluid is not hazardous or toxic, a simple bubbler apparatus could be used to test disk integrity by connecting the bubbler to the disk/valve area. The control efficiency of the disk valve combination is assumed to be 100 percent for fugitive emissions. If the disk integrity is not maintained or if the disk is not replaced after overpressure relief, the control efficiency would be lowered. The disk/valve combination has no effect on emissions which result from overpressure relieving.

4.2.3.2 Resilient Seat Relief Valves. Manufacturers of relief valves state that resilient seat or "O-ring" relief valves provide better reseat qualities compared to standard relief valves. No test data are available to verify these statements. These improvements would have no effect on overpressure emissions or fugitive emissions due to seal failure or "simmering".

4.2.3.3 Closed Vent Systems. A closed vent system can be used to transport the discharge or leakage of pressure relief devices to a control device such as a flare. Since overpressure discharges as well as fugitive emissions are routed to the control device, it must be sized appropriately. A larger pressure relief device may be required for use with a closed vent system. The control efficiency of a closed vent system is dependent on the effectiveness of the control device. Typical flare systems may be only

60 percent effective for fugitive emission destruction.[28] This efficiency reflects the fact that many flare systems are not of optimum design. Flares that are designed to handle large volumes of vapors associated with overpressure releases may also be used to handle low volumes of fugitive emissions. With such designs, optimum mixing is not achieved because the vent gas exit velocity is low and large flares generally cannot properly inject steam into low volume streams.[29] A properly designed flare system typically exhibits a 99 percent hydrocarbon destruction efficiency.[30] Closed vent systems for pressure relief devices are used in existing SOCMI processes especially where the emissions may be hazardous or toxic.

4.2.4 Open-Ended Valves

Fugitive emissions from open-ended valves are caused by leakage through the seat of the valve. Emissions may also occur through the stem and gland of the valve, and these emissions may be controlled by methods described for valves in Section 4.1.2. Approximately 28 percent of SOCMI valves (excluding safety/relief and check valves) in VOC service are open-ended. They include drain, purge, sample, and vent valves. Fugitive emissions from open-ended valves can be controlled by installing a cap, plug, flange, or second valve to the open end of the valve. In the case of a second valve, the upstream valve should always be closed first after use of the valves. Each time the cap, plug, flange, or second valve is opened, any VOC which has leaked through the first valve seat will be released. These emissions have not been quantified. The control efficiency will be dependent on the frequency of removal of the cap or plug. Caps, plugs, etc. for open-ended valves do not affect emissions which may occur during use of the valve. These emissions may be caused by line purging for sampling, draining or venting through the open-ended valve. Caps, plugs, flanges, or second valves for open-ended valves are required by California regulations.[31]

4.2.5 Sampling Connections

Fugitive emissions from sampling connections occur as a result of purging the sampling line in order to obtain a representative sample of the process fluid. Approximately 25 percent of open-ended valves are used for sampling connections.[32] Fugitive emissions from sampling connections can be reduced by using a closed loop sampling system. The closed loop system is designed so that the purged fluid is returned to the process at a point of lower pressure. A throttle valve or other device is required to induce the pressure drop across the sample loop. Closed loop sampling is assumed to be 100 percent effective for controlling fugitive emissions. The purged fluid could also be directed to a control device such as a flare. In this case the control efficiency would be dependent on the flare efficiency for hydrocarbon destruction. Since some pressure drop is required to purge sample through the loop, low pressure processes or tankage may not be amenable to closed loop sampling. Safety requirements may prohibit closed loop sampling in some instances.

4.2.6 In-Line Valves

Fugitive emissions from valves occur at the stem or gland area of the valve body. Diaphragm and bellows seal valves do not have a stem or gland and therefore are not prone to fugitive emissions. They are generally used where hazardous or toxic process fluids are present and fugitive emissions must be eliminated. Their control effectiveness is approximately 100 percent, although a failure of the diaphragm or bellows may cause large temporary emissions. The applicability of these types of valves is limited. They may not be suitable for many applications because of process conditions or cost consideration.

4.2.7 Effectiveness of Equipment Specifications

In order to quantify the environmental and economic impacts of applying controls, the control efficiency must be determined. In some cases, there are many complicating factors which must be considered in estimating control efficiency. For example, the efficiency of caps or plugs for open-ended valves is dependent on 1) the frequency of removal of the cap or plug, and 2) the emission rate through the valve seat. Estimated control efficiencies for various equipment modifications are shown in Table 4-7. These estimates represent the maximum emission reduction possible for the equipment modifications. In some instances, the actual emission reduction will depend on other factors such as the efficiency of control devices attached to closed vent systems. Carbon absorption or vapor recovery systems would approach 100 percent efficiency, but flares may be only 60 percent effective for hydrocarbon destruction. The estimates of effectiveness shown in Table 4-7 were used to calculate environmental and economic impacts of regulatory alternatives in Chapters 7 and 8 of this document.

TABLE 4-7. EFFECTIVENESS OF EQUIPMENT MODIFICATIONS

Source type/ equipment modification	Control efficiency (%)
Pumps	
Sealless pumps	100
Double mechanical seals/closed vent system	∿100[a]
Closed vent system on seal area	∿100[a]
Compressors	
Double mechanical seals/closed vent system	∿100[a]
Closed vent system on seal area	∿100[a]
Safety/relief valves	
Closed vent system	60[b]
Rupture disks	100
Open-ended lines	
Caps, plugs, blinds, second valves	100 [c]
Sampling connections	
Closed loop sampling	100
In-line valves	
Diaphragm valves	100
Bellows-sealed valves	100

[a] Although a control efficiency is not attained in all cases, it is achievable in some cases.

[b] This control effectiveness reflects the fact that a closed vent system is normally sized for emergency relief.[33]

[c] This control efficiency reflects the use of these devices downstream of an initial valve with VOC on one side and atmosphere on the other.

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5. MODIFICATION AND RECONSTRUCTION

In accordance with the provisions of the Code of Federal Regulation Title 40, Sections 60.14 and 60.15 (40 CFR 60.14 and 60.15), an "existing facility" can become an affected facility and, subsequently, subject to the standards of performance if it is modified or reconstructed. An existing facility, as defined in 40 CFR 60.2, is a facility of the type for which standards of performance have been promulgated and the construction or modification of which was begun prior to the proposal date of the applicable standards.

The applicability of provisions 40 CFR 60.14 and 60.15 to the SOCMI, and the conditions, as outlined in these provisions, under which existing facilities could become subject to standards of performance are discussed below.

5.1 GENERAL DISCUSSION OF MODIFICATION AND RECONSTRUCTION PROVISIONS

5.1.1 Modification

"Modification" is defined in 40 CFR 60.14 (a) as any physical or operational change of an existing facility which increases the emission rate of any pollutant to which a standard applies. Exceptions to this definition are presented in paragraphs (e) and (f) of Section 60.14. These exceptions are as follows:

> Paragraph (e) - Physical or operational changes to an existing facility which will not be considered modifications are specified in this portion of Section 60.14. These changes include:
>
> a. Routine maintenance, repair, and replacement.
> b. An increase in the production rate not requiring a capital expenditure as defined in Section 60.2 (bb).

c. An increase in the hours of operation.

d. Use of an alternative fuel or raw material if prior to the standard the existing facility was designed to accommodate that alternate fuel or raw material.

e. The addition or use of any system or device whose primary function is the reduction of air pollutants, except when an emission control system is removed or replaced by a system considered to be less efficient.

f. Relocation or change in ownership.

Paragraph (f) - This paragraph provides for superceding any conflicting provisions of this section.

Upon modification, an existing facility becomes an affected facility for each pollutant to which a standard applies and for which there is an increase in the emission rate to the atmosphere.

5.1.2 Reconstruction

Under the provisions of Section 60.15, an existing facility becomes an affected facility upon reconstruction, irrespective of any change in emission rate. Generally, reconstruction is considered to occur upon the replacement of components if the fixed capital cost of the new components exceeds 50 percent of the fixed capital cost that would be required to construct a comparable entirely new facility, and it is economically and technically feasible for the facility to comply with the applicable standards of performance. The final judgments on what replacement constitutes reconstruction and when it is technologically and economically feasible to comply with the applicable standards of performance is made by the Administrator. The Administrator's final determinations are made on the following bases:

(1) comparison of the fixed capital costs of the replacement components and a newly constructed comparable facility,

(2) the estimated life of the facility after the replacements compared to the life of a comparable entirely new facility,

(3) the extent to which the components being replaced cause or contribute to the emissions from the facility, and

(4) any economic or technical limitations on compliance with applicable standards of performance which are inherent in the proposed replacements.

The purpose of this provision is to ensure that an owner or operator does not perpetuate an existing facility by replacing all but vestigial components, support structures, frames, housing, etc., rather than totally replacing it in order to avoid subjugation to applicable standards of performance. In accordance with Section 60.5, EPA will, upon request, determine if the action taken constitutes construction (including reconstruction).

5.2 APPLICABILITY OF MODIFICATION AND RECONSTRUCTION PROVISIONS TO THE SOCMI

5.2.1 Modification

Changes in operating conditions would mean that a facility would be subject to new source standards of performance if the changes made cause increased emissions. Under these conditions the facility becomes a modified facility. Several changes in operating conditions that could be encountered in an organic chemical plant are presented below. The possible effects of these changes on emissions are presented.

Routine changes and additions of fugitive emission sources are commonly made to increase ease of maintenance, to increase productivity, to improve plant safety, and to correct minor design flaws. These additions of fugitive emission sources would cause an increase in fugitive emissions. However, fugitive emissions from other sources could be reduced to compensate for this increase.

The replacement of a potential fugitive emission source such as a pump or valve commonly occurs in an organic chemical plant. If such a source is replaced with an equivalent source (such as is done during routine repair and replacement), the fugitive emissions from the facility should not increase because the number of potential sources in the same vapor pressure service (handling the same organic chemical) remains unchanged.

Process equipment pieces such as heat exchangers, reactors, distillation columns, reboilers, filters and separators, or new control loops are commonly added to existing facilities in the organic chemical industry to increase the capacity of or to optimize a process. The addition of this equipment would normally increase fugitive emissions from a facility due to the increased number of potential emission sources (pumps, valves, sampling connections, etc.) that are associated with the process equipment.

In some cases a facility in the organic ehcmical industry can be converted from the production of one chemical to the production of a second chemical. This normally occurs when production of the second chemical results in greater profits. In such a case, whenever either the number of fugitive emission sources or the vapor pressure of the second chemical increases during this conversion, the level of VOC emissions from the facility could be expected to increase. As shown in Table 3-1, emission factors for equipment in vapor service are higher than emission factors for equipment in light liquid service which are higher than emission factors for equipment in heavy liquid service. So that, if the vapor pressure of the second chemical is higher than the vapor pressure of the first chemical, the fugitive emissions could be expected to increase.

Changes may be made to a process, although the chemical being produced remains the same. One such case would be a change in catalyst for producing a given chemical. In such a case the level of fugitive emissions would not be expected to change because neither the number of sources nor the vapor pressure of the chemical would change.

In many cases, there may be a desire to increase the capacity of an existing facility. This may be achieved by replacing certain process equipment (pumps, heat exchangers, reactors, etc.) with similar equipment but of larger capacity or addition or process equipment. If this replacement or addition does not increase the number of fugitive emission sources handling the given organic chemical, the level of fugitive emissions would not be expected to increase. However, if the number of sources were to increase due to this replacement or addition, then VOC emissions could be expected to increase.

5.2.2 Reconstruction

When an owner or operator replaces several components of an existing facility, that facility may become subject to applicable standards of performance under the provisions of Section 60.15. For example, if an owner or operator replaces several fugitive emission sources such as pumps, compressors, or sampling loops in an existing facility, and if the fixed capital costs for the new equipment exceeds 50 percent of the costs of all fugitive emissions sources in the unit, the Administrator may determine that reconstruction has occured. Reconstructions may occur as a result of damage caused by fires, explosions, hurricanes, or other catastrophes. They might also result from feedstock changes, product changes, or other major process changes which would require additions or replacement of several fugitive emission sources.

6. MODEL PROCESS UNITS AND REGULATORY ALTERNATIVES

This chapter presents model process unit parameters and alternative emission controls considered for reduction of fugitive emissions from SOCMI sources. The model units were selected to represent the range of processing complexity in the industry. They provide a basis for comparing environmental and economic impacts of the regulatory alternatives. The regulatory alternatives selected provide varying levels of emission control.

6.1 MODEL UNITS

Available data show that fugitive emissions are proportional to the number of potential sources, but are not related to capacity, throughput, age, temperature, or pressure.[1] Therefore SOCMI model units defined for this analysis represent different levels of process complexity (number of sources) rather than different unit sizes.

6.1.1 Sources of Fugitive Emissions

The various potential fugitive emission sources in a SOCMI process unit were described in Chapter 3. Data from petroleum refineries indicate that cooling towers are very small sources of VOC emissions.[2] Differences in SOCMI operating procedures, such as recirculation of process water, might result in cooling tower VOC emissions, but no data are available to verify this. The number of agitator seals in SOCMI is not known. Furthermore, the emission rate from SOCMI agitator seals has not been measured. Since there are no data from similar sources in other industries, no estimates of emission rate can be made. Because of these uncertainties, cooling towers and agitator seals are not included in the Model Units.

6.1.2 Model Unit Parameters

In order to estimate emissions, control costs, and environmental impacts for SOCMI units on a unit specific basis, three model units were developed. The technical parameters for the model units are shown in Table 6-1. These three model units represent the range of emission source populations that may exist in SOCMI process units. The technical parameters were developed from a data base compiled by Hydroscience, Inc.[3] The data base included equipment source counts from 62 SOCMI plants which produce 35 different chemicals. These plant sites represent approximately 5 percent of the total existing SOCMI plants and include large and small capacities, batch and continuous production methods, and varying levels of process complexity. The source counts for the 35 chemicals include pumps, valves, and compressors. These counts were used in combination with the number of sites which produce each chemical in order to determine the average number of sources per site.[4] Hydroscience estimates that 52 percent of existing SOCMI plants are similar to Model Unit A, 33 percent are similar to B, and 15 percent are similar to C.

Data from petroleum refineries indicate that emission rates of sources decrease as the vapor pressure (volatility) of the process fluid decreases. Three classes of volatility have been established based on the petroleum refinery data. These include gas/vapor service, light liquid service, and heavy liquid service.[5] The split between light and heavy liquids for the refinery data is between streams called naphtha and kerosene. Since similar stream names may have different vapor pressures, depending on site specific factors, it is difficult to quantify the light-heavy split. The break point is approximately at a vapor pressure of 0.3 kPa at 20°C. The data collected by Hydroscience were used to estimate the split between gas/vapor and liquid service for each source type.[6] In order to apply emission factors for light and heavy liquid service, it is assumed that one half of SOCMI liquid service sources are in light liquid service. There are no data available on the actual distribution of sources in volatility ranges. It is assumed that all SOCMI packed seal pumps are in heavy liquid service. This assumption is reasonable, since more volatile liquids are

TABLE 6-1. FUGITIVE EMISSION SOURCES FOR THREE MODEL UNITS

	Number of components in model unit[b]		
Equipment component[a]	Model unit A	Model unit B	Model unit C
Pump seals			
Light liquid service			
Single mechanical	5	19	60
Dual mechanical	3	10	31
Sealless	0	1	1
Heavy liquid service			
Single mechanical	5	24	73
Packed	2	6	20
In-line valves			
Vapor service	90	365	1117
Light liquid service	84	335	1037
Heavy liquid service	84	335	1037
Safety/relief valves			
Vapor service	11	42	130
Light liquid service	1	4	13
Heavy liquid service	1	4	14
Open-ended valves and lines[c]			
Vapor service	9	37	115
Light liquid service	47	189	581
Heavy liquid service	48	189	581
Compressor seals	1	2	8
Sampling connections[d]	26	104	320
Flanges	600	2400	7400
Cooling towers	--[e]	--[e]	--[e]

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[a] Equipment components in VOC service only.

[b] 52% of existing units are similar to Model Unit A.
33% of existing units are similar to Model Unit B.
15% of existing units are similar to Model Unit C.

[c] Sample, drain, purge valves and the associated open end.

[d] Based on 25% of open-ended valves. From Ref. 3, pg. IV-3.

[e] Data not available.

more suitable for mechanical seal applications, and newer process units tend to use fewer packed seals. Sampling connections are a subset of the open-ended valve category. Approximately 25 percent of open-ended valves are used for sampling connections.[7] Emissions which occur through the valve stem, gland, and open-end are included in the open-ended valve category. The emission factor for sampling connections applies only to emissions which result from sample purging.

6.2 REGULATORY ALTERNATIVES

The purpose of developing different regulatory alternatives is to provide a basis for determining the air-quality and non air-quality environmental impacts, energy requirements, and the costs associated with varying degrees of VOC fugitive emissions reduction. Regulatory alternatives represent comprehensive programs for reduction of emissions. They are constructed by making different combinations of control techniques described in Chapter 4.

The regulatory alternatives selected for analysis include a "status quo of fugitive emission control" case and three increasingly restrictive levels of emission control requirements. The "status quo" case allows for the analysis of not implementing standards of performance. The three increasingly restrictive control requirements allow for analysis of the impacts of different systems with varying degrees of emission reduction. The requirements for each of these regulatory alternatives are summarized in Table 6-2 and are described below.

6.2.1 Regulatory Alternative I

Alternative I represents the general level of control that would exist in the absence of establishing any VOC fugitive emission control requirement. For this case, SOCMI facilities located in National Ambient Air Quality Standard (NAAQS) attainment areas for oxidant, in general, would not be subject to any requirements. However, some states may require leak detection and repair programs to control fugitive emissions of VOC through prevention of significant deterioration (PSD) statutes. SOCMI facilities located in non-attainment areas for oxidant would be subject to the applicable SIP regulations and other permitting requirements. In some areas control of fugitive VOC emissions may be used to achieve hydrocarbon emission offsets. However, no present or anticipated SIP regulations would be generally applicable to SOCMI. Thus, this alternative is based on current estimations of fugitive emissions.

TABLE 6-2. REGULATORY ALTERNATIVES FOR FUGITIVE EMISSION SOURCES IN SOCMI

	Regulatory alternative							
	I		II		III		IV	
Source type[a]	Monitoring interval	Equipment specification	Monitoring interval	Equipment specification	Monitoring interval	Equipment specification	Monitoring interval	Equipment specification
Pumps								
Light liquids								
with single mechanical seals	None	None	Annually[b]	None	Monthly[b]	None	None[b]	Double seals; degassing vents connected to control device[e]
with double mechanical seals	None	None	Annually[b]	None	Monthly[b]	None	None[b]	Degassing vents connected to control device[e]
with no seals	None	None	None	None	None	None	None	None
Heavy liquids								
with packed seals	None	None	None	None	None	None	None	None
with single mechanical seals	None	None	None	None	None	None	None	None
Valves (in-line)								
Gas	None	None	Quarterly	None	Monthly	None	Monthly	None
Light liquid	None	None	Annually	None	Monthly	None	Monthly	None
Heavy liquid	None	None	None	None	None	None	None	None
Safety/relief valves								
Gas	None	None	Quarterly[c]	None	Monthly[c]	None	None[c]	Upstream rupture disks
Light liquid	None	None	None	None	None	None	None	None
Heavy liquid	None	None	None	None	None	None	None	None
Open-ended valves and lines								
Gas	None	None	Quarterly	Caps[f]	Monthly	Caps[f]	Monthly	Caps[f]
Light liquid	None	None	Annually	Caps[f]	Monthly	Caps[f]	Monthly	Caps[f]
Heavy liquid	None	None	None	Caps[f]	None	Caps[f]	None	Caps[f]
Flanges	None	None	None	None	None	None	None	None
Sampling connections	None	None	None[d]	None	None[d]	None	None[d]	Closed loop sampling
Compressor seals	None	None	Quarterly	None	Monthly	None	None	Seal area or degassing vents connected to control device

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[a] Sources in VOC service.

[b] Plus weekly visual inspection. If liquid leak is observed, instrument monitoring is required to determine if action level is being exceeded.

[c] Monitoring is required after each over pressure release. If it is found to be leaking, the valve will be repaired.

[d] Included in open-ended valves.

[e] Sealless pumps may also be used.

[f] Or blinds, plugs, second valves.

6.2.2 Regulatory Alternative II

This alternative would require leak detection and repair methods as in the petroleum refinery control techniques guideline (CTG), EPA-450/2-78-036. Leak detection would be accomplished by checking equipment components for emissions of VOC using a portable VOC detection instrument to sample and analyze the air in close proximity to the potential leak area. A measured VOC concentration greater than some predetermined level, known as an "action level", would be defined as a leak that would require equipment repair. A measured VOC concentration less than the action level would not require equipment repair. The action level is defined as 10,000 ppmv VOC concentration for all cases.

Quarterly monitoring of compressors, gas service relief valves, inline valves, and open-ended valves would be required. Annual monitoring of light liquid service pumps and valves would be required. Weekly visual inspections of light liquid pump seals would also be required. Leaks detected visually would require instrument monitoring to determine if the action level is exceeded. Relief valve monitoring after over pressure relieving would be required. Open-ended valves would be required to be sealed with a cap, blind, plug, or another valve.

6.2.3 Regulatory Alternative III

Regulatory Alternative III would provide for more restrictive control than Alternative II by increasing the inspections for all applicable equipment to monthly. Increasing the inspections would result in a reduction of emissions from residual leaking sources; i.e., those sources which are found leaking and are repaired and recur before the next inspection and those sources that begin leaking between inspection. Thus, although this alternative is similar in approach to Alternative II, it provides for more emissions reduction. The requirements for weekly visual pump seal inspections, relief valve monitoring after over pressure, and caps for open-ended valves are similar to those for Alternative II.

6.2.4 Regulatory Alternative IV

Alternative IV would require equipment specifications instead of more frequent equipment inspections. This alternative would provide a more restrictive level of control than the other alternatives. Several equipment specifications would be required, including caps for open-ended valves as in

Alternatives II and III. Closed loop sampling techniques would be required and rupture disks would be required on gas service relief valves venting to the atmosphere. Maintenance of the integrity of the disk would be required and replacement of the disk would be required if a failure were detected. No monitoring would be required for relief valves which have rupture disks upstream or which vent to a control device header. Compressor seal areas or degassing vents from seal oil reservoirs, or both, would be required to be connected to a control device with a closed vent system. Pumps in light liquid service would be required to have dual mechanical seals with a barrier fluid system. Degassing vents from the barrier fluid system would be required to be connected to a control device with a closed vent system.

6.3 REFERENCES

1. Wetherold, R. and L. Provost. (Radian Corporation.) Emission Factors and Frequency of Leak Occurence for Fittings in Refinery Process Units. (Prepared for U. S. Environmental Protection Agency.) Research Triangle Park, N. C. Publication No. EPA-600/2-79-044. February 1979. pp. 11-49.
2. Radian Corporation. Assessment of Atmospheric Emissions from Petroleum Refining, Appendix B: Detailed Results. (Prepared for U. S. Environmental Protection Agency.) Research Triangle Park, N. C. Publication No. EPA-600/2-80-075c. April 1980. pp. 300-321.
3. Erikson, D. G. and V. Kalcevic. (Hydroscience, Inc.) Emissions Control Options for the Synthetic Organic Chemicals Manufacturing Industry. (Prepared for U. S. Environmental Protection Agency.) Research Triangle Park, N. C. EPA Contract No. 68-02-2577 February 1979. pp. IV-1, IV-2.
4. Reference 3, p. II-9-13.
5. Reference 1, pp. II-23.
6. Reference 3, p. II-10.
7. Reference 3, p. IV-8.

7. ENVIRONMENTAL IMPACT

The environmental impacts that would result from implementing the regulatory alternatives being considered in this study are examined in this chapter. Included in this chapter are estimates of the controlled VOC fugitive emissions and the incremental reductions in uncontrolled VOC emissions that could be achieved under each of the alternatives. Also, the impacts of these regulatory alternatives on water quality, waste water generation and treatment, solid waste generation and treatment or disposal, and energy consumption or savings are discussed.

7.1 IMPACT ON ATMOSPHERIC EMISSIONS

Implementation of Regulatory Alternatives II, III, or IV, would reduce VOC fugitive emissions from the SOCMI. To quantify reductions, the controlled VOC emission levels from emission sources in the model units (described in Chapter 6) were estimated for each alternative. These emission levels are presented below for individual emission sources, for model units in SOCMI, and then for SOCMI as a whole.

7.1.1 Emission Source Characterization

As indicated in Chapter 6, a SOCMI model unit typically consists of several types of process equipment that contribute to fugitive VOC emissions. Under Regulatory Alternative I (baseline case), all these sources are "uncontrolled" emission sources. However, if Regulatory Alternative II, III, or IV were implemented, the emissions from some uncontrolled sources would be reduced; these sources would subsequently become "controlled" sources. Both the controlled and uncontrolled sources are important because the total fugitive VOC emissions from the model units and ultimately the SOCMI are the sum of emissions from both types of sources.

7.1.2 Development of VOC Emission Levels

The uncontrolled emission levels were previously presented in Chapter 3 (Table 3-1). Controlled emission levels were developed for those sources that would be controlled by the implementation of a regulatory alternative. These controlled fugitive emission levels were calculated by multiplying the uncontrolled emissions from this equipment by a "control efficiency" presented in Chapter 4, Tables 4-2 through 4-4. The resulting controlled VOC emission factors for each source are presented in Tables 7-1, 7-2, and 7-3 for Regulatory Alternatives II, III, and IV, respectively.

To arrive at the controlled VOC emission factors, the total VOC fugitive emissions from Model A, Model B, and Model C units in the SOCMI were determined under each regulatory alternative. Initially, emissions from each source type within a model unit were estimated by using the model unit equipment inventories presented in Table 6-1 and the source emission factors presented in Tables 7-1, 7-2, and 7-3. These emissions estimates were then used to estimate the VOC fugitive emissions from each of the three model units. An example calculation is presented in Table 7-4 to illustrate the procedure used. The example is an estimate of the total VOC fugitive emissions from a model unit under Regulatory Alternative II. The total VOC fugitive emissions calculated for the respective model units under each regulatory alternative are presented in Table 7-5. Also presented in this table are the average reductions (expressed in percentages) in the baseline emission levels that result from implementing Regulatory Alternatives II, III, or IV. Incremental reductions in fugitive emission levels achieved by implementing the alternatives are also presented in Table 7-5.

7.1.3 Future Impact on VOC Fugitive Emissions

In order to assess the future impacts of the various regulatory alternatives on VOC fugitive emissions from the SOCMI, the levels of these emissions were estimated for a period of five years after implementation of a regulatory alternative. These emissions were estimated by using:

1) the emission factors presented in Tables 7-1, 7-2, and 7-3;
2) the industry population for the assumed base year of 1980;

TABLE 7-1. EMISSION FACTORS FOR SOURCES CONTROLLED UNDER REGULATORY ALTERNATIVE II

Uncontrolled emission source	Inspection interval[a]	Uncontrolled[b] emission factor, kg/hr	Correction factors A[c]	B[d]	C[e]	D[f]	Control efficiency (AxBxCxD)	Controlled[g] emission factor, kg/hr
Pumps								
Light liquid service	Yearly	0.120	0.87	0.80	0.98	0.92	0.63	0.044
Valves								
Gas service	Quarterly	0.021	0.98	0.90	0.98	0.99	0.86	0.003
Light liquid service	Yearly	0.010	0.84	0.80	0.98	0.94	0.62	0.004
Safety/relief valves								
Gas service	Quarterly	0.160	0.69	0.90	0.98	0.97	0.59	0.067
Compressors	Quarterly	0.440	0.84	0.90	0.98	0.97	0.72	0.126

[a] From Table 6-2.

[b] From Table 3-1.

[c] Theoretical maximum control efficiency.[1]

[d] Leak occurrence and reoccurrence correction factor - assumed to be 0.80 for yearly inspection, 0.90 for quarterly inspection, and 0.95 for monthly inspection.[2]

[e] Non-instantaneous repair correction factor - for a 15-day maximum allowable repair time, the 7.5-day average repair time yields a 0.98 yearly correction factor [365 - (15/2)] ÷ 365.[3]

[f] Imperfect repair correction factor - calculated as 1 - (f ÷ F). Where f = average emission rate for sources at 1000 ppm and F = average rate for emission sources greater than 10,000 ppm.[4,5]

[g] Controlled emission factor = uncontrolled emission factor x [1 - (A x B x C x D)].

TABLE 7-2. EMISSION FACTORS FOR SOURCES CONTROLLED UNDER REGULATORY ALTERNATIVE III

Uncontrolled emission source	Inspection interval[a]	Uncontrolled[b] emission factor, kg/hr	Correction factors				Control efficiency (AxBxCxD)	Controlled[g] emission factor, kg/hr
			A[c]	B[d]	C[e]	D[f]		
Pumps								
Light liquid service	Monthly	0.120	0.87	0.95	0.98	0.92	0.75	0.030
Valves								
Gas service	Monthly	0.021	0.98	0.95	0.98	0.99	0.90	0.002
Light liquid service	Monthly	0.010	0.84	0.95	0.98	0.94	0.74	0.003
Safety/relief valves								
Gas service	Monthly	0.160	0.69	0.95	0.98	0.97	0.62	0.061
Compressors	Monthly	0.440	0.84	0.95	0.98	0.97	0.76	0.108

[a] From Table 6-2.

[b] From Table 3-1.

[c] Theoretical maximum control efficiency.[6]

[d] Leak occurrence and reoccurrence correction factor - assumed to be 0.80 for yearly inspection, 0.90 for quarterly inspection, and 0.95 for monthly inspection.[7]

[e] Non-instantaneous repair correction factor - for a 15-day maximum allowable repair time, the 7.5-day average repair time yields a 0.98 yearly correction factor [365 - (15/2)] ÷ 365.[8]

[f] Imperfect repair correction factor - calculated as 1 - (f ÷ F). Where f = average emission rate for sources at 1000 ppm and F = average rate for emission sources greater than 10,000 ppm.[9,10]

[g] Controlled emission factor = uncontrolled emission factor x [1 - (A x B x C x D)].

TABLE 7-3. EMISSION FACTORS FOR SOURCES CONTROLLED UNDER REGULATORY ALTERNATIVE IV

Uncontrolled emission source	Inspection interval[a]	Uncontrolled[b] emission factor, kg/hr	Correction factors				Control efficiency (AxBxCxD)	Controlled[g] emission factor, kg/hr
			A[c]	B[d]	C[e]	D[f]		
Pumps								
Light liquid service	None	0.120	NA[h]	NA	NA	NA	-	0.0[i]
Valves								
Gas service	Monthly	0.021	0.98	0.95	0.98	0.99	0.90	0.002
Light liquid service	Monthly	0.010	0.84	0.95	0.98	0.94	0.74	0.003
Safety/relief valves								
Gas service	None	0.160	NA	NA	NA	NA	-	0.0
Compressors	None	0.440	NA	NA	NA	NA	-	0.0[i]
Sampling connections	None	0.015	NA	NA	NA	NA	-	0.0

[a] From Table 6-2.

[b] From Table 3-1.

[c] Theoretical maximum control efficiency.[11]

[d] Leak occurrence and recurrence correction factor - assumed to be 0.80 for yearly inspection, 0.90 for quarterly inspection, and 0.95 for monthly inspection.[12]

[e] Non-instantaneous repair correction factor - for a 15-day maximum allowable repair time, the 7.5-day average repair time yields a 0.98 yearly correction factor [365 - (15/2)] ÷ 365.[13]

[f] Imperfect repair correction factor - calculated as 1 - (f ÷ F). Where f = average emission rate for sources at 1000 ppm and F = average rate for emission sources greater than 10,000 ppm.[14,15]

[g] Controlled emission factor = uncontrolled emission factor x [1 - (A x B x C x D)].

[h] Since the equipment associated with this regulatory alternative essentially eliminates fugitive emissions, these correction factors are not applicable.

[i] Emissions from pumps and conpressors equipped with double seals and vents to a 95 percent control device are very small and are assumed to be zero for calculation purposes.

TABLE 7-4. EXAMPLE CALCULATION OF VOC FUGITIVE EMISSIONS FROM MODEL UNIT A UNDER REGULATORY ALTERNATIVE II

	Number of sources in model unit[a] (N)	Emission factor,[b] kg/hr-source (E)	Emissions from sources, kg/hr (N x E)
Emission Source:[c]			
Pumps			
Light liquid[d] single mechanical seal	5	0.044	0.220
Light liquid[d] dual mechanical seal	3	0.044	0.132
Heavy liquid[e] single mechanical seal	5	0.020	0.100
Heavy liquid[e] packed seal	2	0.020	0.040
In-line valves			
Vapor service	90	0.003	0.270
Light liquid[d] service	84	0.004	0.336
Heavy liquid[e] service	84	0.0003	0.025
Safety/relief valves			
Vapor service	11	0.067	0.737
Light liquid[d] service	1	0.006	0.006
Heavy liquid[e] service	1	0.009	0.009
Open-ended valves[f]			
Vapor service	9	0.003	0.027
Light liquid[d] service	47	0.004	0.188
Heavy liquid[e] service	48	0.003	0.014
Compressors	1	0.126	0.126
Sampling connections	26	0.015	0.390
Flanges	600	0.0003	0.180
	Total emissions		2.800

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[a] Model units are characterized in Table 6-1.

[b] Emission factors from Tables 3-1 and 7-1.

[c] Sources in VOC service.

[d] Light liquid service means that the fugitive emission source contains a liquid which has a vapor pressure equal to or greater than 0.3 kPa at 20°C.

[e] Heavy liquid service means that the fugitive emission source contains a liquid which has a vapor pressure less than 0.3 kPa at 20°C.

[f] Open-ended valve factor is equivalent to the in-line valve factor because capping the open end is assumed to eliminate emissions from this source.

TABLE 7-5. ESTIMATED EMISSIONS AND EMISSION REDUCTIONS ON A MODEL UNIT BASIS[a]

Regulatory Alternative	Estimated emissions,[b,c] (Mg/yr) Model unit			Average percent reduction from emissions estimated under Regulatory Alternative I	Average incremental percent reduction in emissions
	A	B	C		
I	67	260	800	--	--
II	24	94	290	63	63
III	21	80	250	69	6
IV	8	34	106	87	18

[a] The emissions and percentage reductions presented in this table were calculated using the following:

- controlled and uncontrolled emission factors (see Tables 7-1, 7-2, and 7-3), and
- emission sources given in Table 6-1.

[b] A year is assumed to be equivalent to 8,760 hours.

[c] 1.0 Mg/yr = 2200 pounds/yr

3) annual replacement of the industry population based on a twenty-year equipment life; and[16]

4) annual growth rate of 5.9 percent for the industry.[17]

Using these bases and the techniques presented in Appendix E, the total number of model units in operation in 1981 were estimated to be 148. In 1985 the total number of model units were estimated to be 831.[18]

Under Regulatory Alternative I, total VOC fugitive emissions from model units were estimated to increase from 35 to 199 gigagrams per year (Gg/yr) during the same five-year (1981-1985) period (see Table 7-6). In the same time period, implementation of Regulatory Alternative II could be expected to reduce the baseline case (Regulatory Alternative I) fugitive emissions by 63 percent. Implementation of Regulatory Alternative III would reduce the baseline emissions by 69 percent. As Table 7-5 indicates, Regulatory Alternative IV, the most stringent of all the alternatives, would reduce the baseline emissions by about 87 percent.

7.2 IMPACT ON WATER QUALITY

In the absence of standards to reduce fugitive emissions of VOC from SOCMI and under normal equipment operation, liquid leaks from various equipment components could increase the quantity of wastewater generated by a "typical" SOCMI facility. Under Regulatory Alternative I, liquid leaks could originate from pumps and process valves in light or heavy liquid service as well as valves on open-ended lines in light or heavy liquid service and enter the wastewater system as runoff. Although the uncontrolled emission rates for these sources are given in Chapter 3, the gas-liquid split of these emissions is not defined. Consequently, the increase in wastewater from SOCMI due to liquid leaks from potential fugitive emission sources cannot be quantified.

Implementation of Regulatory Alternative II could reduce the wastewater from a "typical" SOCMI facility by reducing the fugitive liquid emissions resulting under Alternative I. The reduced emissions would be due to the use of caps, plugs or second valves on open-ended lines in gas and light or heavy liquid service. For example, caps, plugs, or second valves required under Alternative II would reduce the VOC fugitive emission rate from open-ended lines in light or heavy liquid service from 0.01 kg/hr under Alternative I to 0.004 kg/hr. This reduction would reflect a reduction in gaseous emissions and liquid leaks. Since the gas-liquid split of the emission from a given source is site specific, the impact of Alternative II on wastewater from SOCMI cannot be quantified. However, it is likely that this impact would be minor.

Implementation of Alternative III would result in impacts on wastewater from SOCMI similar to those resulting from Alternative II. However, the impacts under Alternative III would be more pronounced due to the more frequent inspection intervals required by this alternative. The more frequent intervals would reduce the VOC fugitive emission rate from valves in light or heavy liquid service from 0.004 kg/hr under Alternative II to 0.003 kg/yr under Alternative III. Similarly, the fugitive emission rate from pumps in light liquid service would be 0.044 kg/hr under Alternative II and 0.03 kg/hr under Alternative III. Consequently, the potential for the production of liquid leaks which would be added to the wastewater from SOCMI by possible fugitive emission sources would be less under Alternative III than under Alternative II.

Of the alternatives being considered, Regulatory Alternative IV could have the greatest impact on the quality of water that is discharged from a "typical" SOCMI facility. Implementation of this alternative could have positive (and possibly some negative) impacts on wastewater depending on the specific control device requirements at each unit. Implementation of Regulatory Alternative IV could reduce the amount of wastewater from a SOCMI facility by reducing the fugitive liquid emissions resulting under Alternative I. The reduction of these emission levels is primarily due to the reduction of leaks from equipment in light liquid service, e.g., from the use of double mechanical seals for pumps and closed loop sampling. Under Regulatory Alternative IV, a double mechanical seal-degassing vent arrangement reduces the emission rate of a pump seal in light liquid service under Regulatory Alternative I from 0.12 to 0.0 kg/hr. A portion of this emission reduction would be a reduction in liquids leaked to the ground or ditch. However, the amount of liquids leaked to the ground or ditch that could enter a plant wastewater system is not known.

TABLE 7-6. TOTAL VOC FUGITIVE EMISSIONS FROM AFFECTED MODEL UNITS FOR REGULATORY ALTERNATIVES

Year	Number of affected model units[a]			Total fugitive emissions estimated under Regulatory Alternative[b,c]			
	A	B	C	I (Gg/yr)	II (Gg/yr)	III (Gg/yr)	IV (Gg/yr)
1981	77	49	22	35.4	12.9	11.0	4.6
1982	158	100	46	73.1	26.7	22.8	9.5
1983	244	155	71	113.0	41.2	35.2	14.8
1984	335	213	97	155	56.5	48.3	20.2
1985	432	274	125	199	72.8	62.1	26.0

[a] The bases for estimating the number of model units, as detailed in Appendix E, are:

- an industry growth rate of 5.9 percent per year,
- unit replacement based on a 20-year equipment life, and
- a base year (1980) total of 872 Model A, 554 Model B, and 252 Model C Units.

[b] Estimated total VOC fugitive emissions from Model Units A, B, and C.

[c] Does not include emissions from units in existence prior to 1981.

Implementation of Regulatory Alternative IV could also result in a negative impact on water quality due to the operation of a control device which "captures" the fugitive VOC's. If a carbon adsorption device were used to capture any VOC released at the degassing vent and if the carbon is regenerated at the unit, a wastewater containing suspended solids and some dissolved organics could be produced during the carbon regeneration process. The use of a refrigeration process as the ultimate control device could possibly result in a condensate containing dissolved organics. The wastewater flow rates would be quite small and would generally be suitable for treatment in the existing unit wastewater treatment process. Overall, the impacts, both positive and negative, of Alternative IV on wastewaters from SOCMI would be minor.

7.3 IMPACT ON SOLID WASTE

In the absence of standards to reduce fugitive emissions of VOC from SOCMI and under normal operation, solid wastes that could result from SOCMI include replaced seals, packing, rupture disks, equipment components such as pumps and valves, spent catalysts, and polymerization products. Metal solid wastes such as mechanical seals, rupture disks and valve parts could be sold as scrap metal to companies which can recycle the metal. This would help to minimize the impact on solid waste. The quantity of used valve packings and used batteries for monitoring instruments would not significantly contribute to solid waste.

Implementation of Alternatives II and III would require the use of caps, plugs, or second valves on open-ended lines in light or heavy liquid service, and more frequent monitoring intervals. Implementing either of these alternatives would have no greater impact on solid waste than Alternative I. This is due to the relatively long life of caps, plugs, and second valves on open-ended lines as well as the ability to sell discarded components such as valves, mechanical seals, and rupture disks as scrap metal.

Implementation of Regulatory Alternative IV could result in the generation of solid waste if carbon adsorption were used as a control device and if the carbon were discarded instead of being regenerated. However, the VOC emissions from the pump and compressor vents are small streams, so that carbon requirements would be very low. Furthermore, the carbon could be sent back to the manufacturer for regeneration, thereby reducing the solid waste problem at the facility. It is anticipated that the manufacturer could incinerate or commercially dispose of any carbon that could not be regenerated (such as carbon fines) without any serious environmental problems. Consequently, the negative impact of implementing Alternative IV would be minor.

7.4 ENERGY IMPACT

Regulatory Alternatives II, III and IV call for passive controls on equipment handling VOC streams (i.e., pump seals, process vent enclosures, degassing vents, etc.); so implementing any of these alternatives will not significantly increase the energy usage of a typical SOCMI plant. If a control device such as a carbon adsorption system were used, steam (or another hot regenerating medium) would be needed to regenerate the carbon at the unit; however, the energy requirements would be quite small. The energy requirements of vapor recovery systems and of closed loop sampling would also be small. Any of the alternatives would increase efficiency of raw material usage. Because the raw materials for SOCMI are also energy sources, implementation of any of the alternatives being considered will result in a positive energy impact.

The average energy value of the fugitive VOC emissions from SOCMI is estimated to be approximately 31 x 10^6 joule/kg.[19] The energy savings resulting from the fugitive VOC emission reductions associated with Alternatives II, III, and IV are presented in Table 7-7. Because Alternative IV is the most stringent, it will result in the greatest emission reduction. As Table 7-7 indicates, implementation of this regulatory alternative would reduce the uncontrolled fugitive emissions by 173 Gg in the fifth year and by a total of 520 Gg over a five-year period after implementation. These "recovered" VOC emissions have a total energy value of 1.55 x 10^{13} joules based on an average heating value of 31 x 10^6 joule/kg. Assuming an energy value of 5.8 x 10^6 Btu per barrel of crude oil,[20] the energy value of the total fugitive emissions recovered over the five-year period is approximately equal to 2.5 million barrels of crude oil under Regulatory Alternative IV. This corresponds to an average daily savings of 1390 bbl/day of crude oil over the five-year period.

TABLE 7-7. ENERGY IMPACT OF EMISSION REDUCTIONS FOR REGULATORY ALTERNATIVES

Year	Reduction from baseline emissions under Regulatory Alternatives, Gg[a]			Energy value of emission reductions under Regulatory Alternatives, terajoule[b]			Crude oil equivalent of emission reductions, thousand barrels		
	II	III	IV	II	III	IV	II[c]	III[c]	IV[c]
1981	22.4	24.4	30.8	694	756	955	113	124	156
1982	46.4	50.3	63.6	1,440	1,560	1,970	235	255	322
1983	71.8	77.8	98.2	2,230	2,410	3,040	364	394	497
1984	98.3	106	135	3,050	3,290	4,180	498	538	683
1985	127	137	173	3,940	4,250	5,360	644	695	876
5-year total	366	396	500	11,350	12,270	15,500	1,855	2,005	2,530

[a] Estimated total VOC fugitive emission reduction from Model Units A, B, and C.

[b] Based on 1.55×10^{13} joules/kg[21]: This may be slightly over estimated if safety/relief valves are controlled by a closed vent and flare system.

[c] Based on 5.8×10^{6} Btu/bbl crude oil.

7.5 OTHER ENVIRONMENTAL CONCERNS

7.5.1 Irreversible and Irretrievable Commitment of Resources

Implementation of any of the various alternatives is not expected to result in any irreversible or irretrievable commitment of resources. As previously noted, the regulatory alternatives should help to save resources due to the energy savings associated with the reductions in emissions.

7.5.2 Environmental Impact of Delayed Standards

As it was indicated above, implementation of the standards will only have minor impacts on water and solid wastes. Consequently, delaying the standards would have essentially no impact on these problems. However, a delay in implementing the alternatives would have a greater impact on air pollution and associated energy losses. The air and energy impacts of delayed standards are shown in Table 7-7. The emission reductions and associated energy savings shown would be irretrievably lost at the rates shown for each of the five years.

7.6 REFERENCES

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8. COST ANALYSIS

8.1 COST ANALYSIS OF REGULATORY ALTERNATIVES

8.1.1 Introduction

The costs of implementing the regulatory alternatives for controlling fugitive emissions of volatile organic compound (VOC) from the synthetic organic chemicals manufacturing industry (SOCMI) are presented in the following sections. Detailed descriptions of the model units and regulatory alternatives treated in this cost analysis are presented in Chapter 6.

8.1.2 New Facilities

8.1.1.1 Capital Costs. The bases for the capital costs for the model units are presented in Table 8-1. The capital cost estimates for each model unit under each regulatory alternative are given in Table 8-2. Regulatory Alternative I requires no control of VOC emissions. Consequently there are no capital costs associated with this alternative.

The capital costs for the model units are the same under Regulatory Alternatives II and III, since the only change is the monitoring frequency. These costs include the purchase of two VOC monitoring instruments and caps for all open-ended lines. It is assumed that one monitoring instrument is used as a standby spare.

Under Regulatory Alternative IV, like II and III, two monitoring instruments and caps for all open-ended lines would be purchased. In addition, several other capital costs would be incurred. All single seal pumps in light liquid service would require double mechanical seals at a cost of $575/pump. A barrier fluid system ($1500/pump) would also be required in conjunction with the double mechanical seals. Existing pumps with double mechanical seals are assumed to have a barrier fluid system already incorporated. Hence, there would be no additional capital expenditure for the double seals or barrier fluid system.

TABLE 8-1. CAPITAL COST DATA

Item	Cost Value Used in Analysis (last quarter 1978$)	Cost Basis	Reference
Monitoring Instrument	2 x 4250 = 8500/model unit	One instrument used as a spare	1,2
Caps for open-ended lines	45/line	Based on installation of a 2.5 cm. screwed valve.[a] Cost (1967) = $12. Cost index = 278.1/113. Installation = 1 hour at $15/hour.	3,4,5,6,7
Dual mechanical seals	575/pump (new)	Seal cost = $560. Single seal credit = $225. Shop installation = $240.	8
	850/pump (retrofit)	Seal cost = $560. Field installation = $290.	9
Barrier fluid system for dual mechanical seals	1500/pump	Pressurized reservoir system = $700. System cooler = $800. Pumps that have dual mechanical seals without regulatory requirement may not have the cost of a barrier fluid system added. The barrier fluid system is assumed to be an integral part of the seal system.	10
Closed vents for degassing reservoirs of compressors and dual seal pumps	6530/compressor	Based on installation of a 122 m length of 5.1 cm. diameter, schedule 40 carbon steel pipe at a cost of $5200; plus three 5.1 cm. cast steel plug valves and one metal gauge flame arrestor at a cost of $1330. These costs include connection of the degassing reservoir to an existing enclosed combustion device or vapor recovery header. Cost of a control device added specifically to control the degassing vents is, therefore, not included.	11
	3265/pump	The costs have the same basis as closed vents for compressors. The cost for pumps is based on the assumption that two pumps (such as a pump and its spare) are connected to a single degassing vent.	12

[a] Lines larger than 2.5 cm may be flanged. Installed cost for blind flanges is estimated to be $30/line.

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TABLE 8-1 (cont.). CAPITAL COST DATA

Item	Cost Value Used in Analysis (last quarter 1978$)	Cost Basis	Reference
Rupture disks for relief valves	1730/relief valve (new)	Cost of rupture disk assembly: one 7.6 cm. rupture disk stainless steel = $195; one 7.6 cm. rupture disk holder, carbon steel = $375; one 0.6 cm. pressure gauge, dial face = $15; one 0.6 cm. bleed valve, carbon steel, gat = $25; installation = $240. To allow in-service disk replacement, a block valve must be installed upstream of the rupture disk. Cost (1967) for one 7.6 cm. gate valve = $240. Cost index = 278.1/113. Installation = 10 hours at $15/hour. To prevent damage to the relief valve by disk fragments, an offset mounting is required. Cost (1967) for one 10.2 cm. tee and one 10.2 cm. elbow = $7.30. Cost index = 278.1/113. Installation = 8 hours at $15/hour.	13,14,15,16,17,18,19
	3110/relief valve (retrofit)	Costs for the rupture disk, holder, and block valve are the same as for the new applications. An additional cost is added to replace the derated relief valve. No credit is assumed for the used relief valve. Cost for one 7.6 cm pressure relief valve, stainless steel body and trim = $500. Cost index = 278.1/113. Installation = 10 hours at $15/hour.	20,21,22,23
Closed loop sampling connections	460/sampling connection	Based on installation of a 6 m. length of 2.5 cm. diameter, schedule 40, carbon steel pipe and three 2.5 cm. carbon steel ball valves. Installation = 10 hours at $15/hour.	24

TABLE 8-2. CAPITAL COST ESTIMATES FOR NEW MODEL UNITS (thousands of last quarter 1978 dollars)

Capital cost item[a]	Regulatory alternative I	II	III	IV
Model Unit A				
1. Monitoring instrument		8.50	8.50	8.50
2. Caps for open-ended lines		4.68	4.68	4.68
3. **Dual mechanical seals**[b].				
· Seals				1.68
· Installation				1.20
4. **Barrier fluid system for dual mech. seals**[c]				7.5
5. Vents for compressor degassing reservoirs				6.53
6. Vents for pump degassing reservoirs				26.1
7. Rupture disks for relief valves				
· Disks				2.14
· Holders, block valves, installation				16.8
8. Closed loop sampling connections				12.0
Total	0.0	13.2	13.2	87.1
Model Unit B				
1. Monitoring instrument		8.50	8.50	8.50
2. Caps for open-ended lines		18.7	18.7	18.7
3. **Dual mechanical seals**[b].				
· Seals				6.36
· Installation				4.56
4. **Barrier fluid system for dual mech. seals**[c]				28.5
5. Vents for compressor degassing reservoirs				13.1
6. Vents for pump degassing reservoirs				94.7
7. Rupture disks for relief valves				
· Disks				8.19
· Holders, block valves, installation				64.4
8. Closed loop sampling connections				47.8
Total	0.0	27.2	27.2	295
Model Unit C				
1. Monitoring instrument		8.50	8.50	8.50
2. Caps for open-ended lines		57.5	57.5	57.5
3. **Dual mechanical seals**[b].				
· Seals				20.1
· Installation				14.4
4. **Barrier fluid system for dual mech. seals**[c]				90.0
5. Vents for compressor degassing reservoirs				52.2
6. Vents for pump degassing reservoirs				297
7. Rupture disks for relief valves				
· Disks				25.4
· Holders, block valves, installation				199
8. Closed loop sampling connections				147
Total	0.0	66.0	66.0	911

[a] From Tables 6-1 and 8-1.

[b] **Cost is for back-to-back arrangement.**

[c] **Pressurized system.**

Also, under Regulatory Alternative IV, compressor seals and pump seals must have the seal oil degassing vents that are connected to a control device such as a vapor recovery system or an enclosed combustion device. The cost is estimated to be $6530 per compressor and $3265 per pump. This cost is based on the assumption that one closed vent system is required for each compressor. Since main pumps and spares are generally located in close proximity to each other, one closed vent system would be required for each pair of pumps. These costs are based on connecting the closed vent system to an existing control device.

The costs of purchasing and installing rupture disks is $1590 per relief valve. Rupture disks would be installed upstream of relief valves in gas service. The cost includes the purchase of a shutoff valve to allow the disk to be replaced after overpressure relief.

The closed loop sampling connection costs are based on an estimate of $460 per sampling connection for installation of 6 meters of pipe and three valves.

8.1.2.2 Annual Costs. With the implementation of Regulatory Alternatives II, III, or IV, visual and/or instrument monitoring of potential sources of fugitive VOC emissions will be required. A summary of the requirements for the different alternatives is presented in Chapter 6. Tables 8-3, 8-4, and 8-5 give the monitoring labor-hour requirements for Regulatory Alternatives II, III and IV, respectively. The labor-hour requirements were calculated by taking the product of the number of workers needed to monitor a component (1 for visual, 2 for instrument), the time required to monitor, the number of components in the model unit, and the number of times the component is monitored per year. Monitoring labor costs were then calculated based on $15 per hour.[25,26,27] Regulatory Alternative III would require the highest annual monitoring costs.

Leak repair labor is the cost of repairing those components in which leaks develop after initial repair. Leaks may be discovered during the

TABLE 8-3. ANNUAL MONITORING AND LEAK REPAIR LABOR REQUIREMENTS FOR REGULATORY ALTERNATIVE II

	Monitoring										Leak repair						
	Number of components per model unit						Monitoring labor-hours required[c]			Estimated number of leaks per year[d]					Leak repair labor-hours required[e]		
Source type	A	B	C	Type of[a] monitoring	Monitoring time,[b] min	Times monitored per year	A	B	C	A	B	C	Repair time, hrs	A	B	C
Pumps (light liquid)																
Single mechanical seals	5	19	60	Instrument Visual	5 0.5	1 52	1.0 2.2	3.2 8.2	10.0 26.0	1	1	3	80[b]	80	80	240
Dual mechanical seals	3	10	31	Instrument Visual	5 0.5	1 52	1.0 1.3	1.7 4.3	5.2 13.4	1	1	2	80[b]	80	80	160
Valves (in-line)																
Gas	90	365	1117	Instrument	1	4	12.0	49.0	149.0	4	15	45	1.13[f]	4.5	17.0	50.9
Light liquid	84	335	1037	Instrument	1	1	2.8	11.2	34.6	3	9	25	1.13[f]	3.4	10.2	28.3
Safety/relief valves (gas service)	11	42	130	Instrument	8	4	11.7	44.3	139.0				0[g]	0	0	0
Valves on open-ended lines[h]																
Gas	9	37	115	Instrument	1	4	1.2	4.9	15.3	1	2	5	1.13[e]	1.1	2.3	5.7
Light liquid	47	189	581	Instrument	1	1	1.6	6.3	19.4	2	6	14	1.13[e]	2.3	6.8	15.8
Compressor seals	1	2	8	Instrument	10	4	1.3	2.7	10.7	1	1	2	40[b]	40	40	80

[a] 2 workers for instrument monitoring, 1 for visual. Ref. 28, p. 4-3.

[b] Ref. 29.

[c] Monitoring labor-hours = number of workers x number of components x time to monitor (total is minimum of 1 hr).

[d] From Table 4-2.

[e] Leak repair labor-hours = number of leaks x repair time.

[f] Weighted average based on 75 percent of the leaks repaired on-line, requiring 0.17 hour per repair, and on 25 percent of the leaks repaired off-line, requiring 4 hours per repair. Ref. 30, p. B-12.

[g] It is assumed that these leaks are corrected by routine maintenance at no additional labor requirements. Ref. 31.

[h] The estimated number of leaks per year for open-ended valves is based on the same percent of sources used for in-line valves. This represents leaks occurring through the stem and gland of the open-ended valve. Leaks through the seat of the valve are eliminated by adding caps for Regulatory Alternatives II, III, IV.

TABLE 8-4. ANNUAL MONITORING AND LEAK REPAIR LABOR REQUIREMENTS FOR REGULATORY ALTERNATIVE III.

	Monitoring									Leak repair						
	Number of components per model unit						Monitoring labor-hours required[c]			Estimated number of leaks per year[d]				Leak repair labor-hours required[e]		
Source type	A	B	C	Type of[a] monitoring	Monitoring time,[b] min	Times monitored per year	A	B	C	A	B	C	Repair time, hrs	A	B	C
Pumps (light liquid)																
Single mechanical seals	5	19	60	Instrument Visual	5 0.5	12 52	10.0 2.2	38.0 8.2	120.0 26.0	1	3	9	80[b]	80	240	720
Dual mechanical seals	3	10	31	Instrument Visual	5 0.5	12 52	6.0 1.3	20.0 4.3	62.0 13.4	1	2	5	80[b]	80	160	400
Valves (in-line)																
Gas	90	365	1117	Instrument	1	12	36.0	146.0	446.8	6	22	68	1.13[f]	6.8	24.9	76.8
Light liquid	84	335	1037	Instrument	1	12	33.6	134.0	414.8	7	25	75	1.13[f]	7.9	28.3	84.8
Safety/relief valves (gas service)	11	42	130	Instrument	8	12	35.2	134.4	416.0				0[g]	0	0	0
Valves on open-ended lines[h]																
Gas	9	37	115	Instrument	1	12	3.6	14.8	46.0	1	3	7	1.13[e]	1.1	3.4	7.9
Light liquid	47	189	581	Instrument	1	12	18.8	75.6	232.4	4	14	42	1.13[e]	4.5	15.8	47.5
Compressor seals	1	2	8	Instrument	10	12	4.0	8.0	32.0	1	1	2	40[b]	40	40	80

[a] 2 workers for instrument monitoring, 1 for visual. Ref. 32.

[b] Ref. 33.

[c] Monitoring labor-hours = number of workers x number of components x time to monitor (total is minimum of 1 hr).

[d] From Table 4-2.

[e] Leak repair labor-hours = number of leaks x repair time.

[f] Weighted average based on 75 percent of the leaks repaired on-line, requiring 0.17 hour per repair, and on 25 percent of the leaks repaired off-line, requiring 4 hours per repair. Ref. 34.

[g] It is assumed that these leaks are corrected by routine maintenance at no additional labor requirements. Ref. 35.

[h] The estimated number of leaks per year for open-ended valves is based on the same percent of sources used for in-line valves. This represents leaks occurring through the stem and gland of the open-ended valve. Leaks through the seat of the valve are eliminated by adding caps for Regulatory Alternatives II, III, IV.

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TABLE 8-5. ANNUAL MONITORING AND LEAK REPAIR LABOR REQUIREMENTS FOR REGULATORY ALTERNATIVE IV.

Source type	Monitoring									Leak repair						
	Number of components per model unit			Type of[a] monitoring	Monitoring time,[b] min	Times monitored per year	Monitoring labor-hours required[c]			Estimated number of leaks per year[d]			Repair time, hrs	Leak repair labor-hours required[e]		
	A	B	C				A	B	C	A	B	C		A	B	C
Pumps (light liquid)																
Single mechanical seals converted to double seals	5	19	60	Instrument Visual	5 0.5	0^f 52	0 2.2	0 8.2	0 26.0	0^f	0^f	0^f	80^b	0	0	0
Dual mechanical seals	3	10	31	Instrument Visual	5 0.5	0^f 52	0 1.3	0 4.3	0 13.4	0^f	0^f	0^f	80^b	0	0	0
Valves (in-line)																
Gas	90	365	1117	Instrument	1	12	36.0	146.0	446.8	6	22	68	1.13^g	6.8	24.9	76.8
Light liquid	84	335	1037	Instrument	1	12	33.6	134.0	414.8	7	25	75	1.13^g	7.9	28.3	84.8
Safety/relief valves (gas service)	11	42	130	Instrument	8	0^f	0	0	0	0^f	0^f	0^f	$0^{f,h}$	0	0	0
Valves on open-ended lines[i]																
Gas	9	37	115	Instrument	1	12	3.6	14.8	46.0	1	3	7	1.13^g	1.1	3.4	7.9
Light liquid	47	189	581	Instrument	1	12	18.8	75.6	232.4	4	14	42	1.13^g	4.5	15.8	47.5
Compressor seals	1	2	8	Instrument	10	0^f	0	0	0	0^f	0^f	0^f	40^b	0	0	0

[a] 2 workers for instrument monitoring, 1 for visual. Ref. 36.

[b] Ref. 37.

[c] Monitoring labor-hours = number of workers x number of components x time to monitor (total is a minimum of 1 hr).

[d] From Table 4-2.

[e] Leak repair labor-hours = number of leaks x repair time.

[f] No monitoring or leak repair required because equipment specifications eliminate leak potential.

[g] Weighted average based on 75 percent of the leaks repaired on-line, requiring 0.17 hour per repair, and on 25 percent of the leaks repaired off-line, requiring 4 hours per repair. Ref. 38.

[h] It is assumed that these leaks are corrected by routine maintenance at no additional labor requirements. Ref. 39.

[i] The estimated number of leaks per year for open-ended valves is based on the same percent of sources used for in-line valves. This represents leaks occurring through the stem and gland of the open-ended valve. Leaks through the seat of the valve are eliminated by adding caps for Regulatory Alternatives II, III, IV.

periodic monitoring required by the regulatory alternatives. The number of estimated leaks and the labor hours required for repair are given in Tables 8-3, 8-4, and 8-5. Leak repair labor was calculated based on \$15 per hour.[40,41,42] Maintenance labor costs would be greatest under Regulatory Alternative III and least under Alternative IV. Costs would be reduced under Alternative IV because the required installation of double mechanical seals with seal oil degassing vents eliminates the most time-consuming repair items.

Administrative and support costs were estimated at 40 percent of the sum of monitoring and leak repair labor costs. Monitoring labor, leak repair labor, and administrative/support costs are recurring annual costs for each Regulatory Alternative.

8.1.2.3 Annualized Costs. The bases for the annualized control costs are presented in Table 8-6. The annualized capital, maintenance, and miscellaneous costs were calculated by taking the appropriate factor from Table 8-6 and applying it to the corresponding- capital cost from Table 8-2. The capital recovery factors were calculated using the equation:

$$CRF = \frac{i(1 + i)^n}{(1 + i)^n - 1}$$

where i = interest rate, expressed as a decimal,

n = economic life of the component, years.

The interest rate used was 10 percent (last quarter 1978). The expected life of the monitoring instrument was 6 years compared to 10 years for other control equipment components. Dual seals and rupture disks were assumed to have a 2 year life.

The implementation of any of the Regulatory Alternatives (except I) will result in the initial discovery of leaking components. It is assumed that fewer leaks will be found at subsequent inspections. The cost of repairing initial leaks was amortized over a 10-year period, since this is a one-time cost. Repair of leaks found at subsequent inspections was included as a recurring annual cost in 8.1.2.2. The estimated percentage of initial leaks per component is shown in Table 4-2. This percentage was applied to the number of components in the model unit under consideration. Fractions were rounded up to the next integer, since in practice it is the whole valve, or seal, that is replaced and not just part of one. The time required to repair each component type is given

TABLE 8-6. DERIVATION OF ANNUALIZED LABOR, ADMINISTRATIVE, MAINTENANCE AND CAPITAL CHARGES

1. Capital recovery factor for capital charges	
• Dual seals and rupture disks	0.58 x capital[a]
• Other control equipment	0.163 x capital[b]
• Monitoring instruments	0.23 x capital[c]
2. Annual maintenance charges	
• Control equipment	0.05 x capital[d]
• Monitoring instruments	$2700[e]
3. Annual miscellaneous charges (taxes, insurance, administration)	
• Control equipment	0.04 x capital[f]
• Monitoring instruments	0.04 x capital[f]
4. Labor charges	$15/hour[g]
5. Administrative and support costs to implement regulatory alternative	0.4 x (monitoring labor + maintenance labor)[h]
6. Annualized charge for initial leak repairs	Σ(estimated number of leaking components per model unit[i] x repair time[i]) x $15/hr[g] x 1.4[h] x 0.163[j]

---

[a] Applies to cost of seals ($335 - incremental cost due to specification of dual seals instead of single seals) and disk ($195) only. Two year life, ten percent interest.

[b] Ten year life, ten percent interest. From Ref. 43, pp. IV-3,4.

[c] Six year life, ten percent interest. From Ref. 44, pp. IV-9,10.

[d] From Ref. 45, pp. IV-3,4.

[e] Includes materials and labor for maintenance and calibration. Cost (last quarter 1977) from Ref. 46, p. 4-3. Cost index = 221.7 ÷ 209.1 (Ref. 47 and 48).

[f] From Ref. 49, pp. IV-3,4,9,10.

[g] Includes wages plus 40 percent for labor-related administrative and overhead costs. Cost (last quarter 1977) from Ref. 50, pp. 4-4,5. Cost index = 190.3 ÷ 180.9 (Ref. 51 and 52).

[h] From Ref. 53, pp. IV-9,10.

[i] Shown in Table 8-7.

[j] Initial leak repair amortized for ten years at ten percent interest.

in Table 8-7. The initial repair cost was determined by taking the product of the number of initial leaks, the repair time, and the labor rate, $15 per hour.[54,55,56] Forty percent was added for administrative and support costs. Finally, the total was multiplied by 0.163, the capital recovery factor. As shown in Table 8-7, the cost of initial leak repair under Regulatory Alternative IV is substantially less for each of the model units than under Alternatives II and III. The main reason for this reduction is the required installation of dual mechanical seals and seal oil degassing vents that reduce the leak potential of pumps and compressors. The repair time for a single pump or compressor seal is very much greater than the repair time for a valve, so that a leak detection and repair program for pumps and compressors would be more labor-intensive.

8.1.2.4 Recovery Credits. The annual VOC emissions, total emission reductions, and annual recovered product credits for each model unit under each Regulatory Alternative are shown in Table 8-8. Regulatory Alternative I represents the uncontrolled emissions from each model unit. The annual emission reduction was calculated by subtracting the controlled emission factor from the uncontrolled emission factor for each source. To obtain an annual rate, the result was multiplied by 8760 hours per year. The recovery credit was calculated at $360 per Mg of recovered product.[57]

8.1.2.5 Net Annualized Costs. The net annualized costs, shown in Tables 8-9, 8-10, and 8-11, were determined by subtracting the annual recovered product credit from the total cost before credit. For example, Model Unit A, under Regulatory Alternative II has a net annualized credit of $3300, as a result of $12,100 in costs and $15,400 for recovery credits.

8.1.2.6 Cost Effectiveness. The cost effectiveness of each regulatory alternative for each model unit is shown in Table 8-12. Regulatory Alternatives II and III have a net annualized credit for all model units, and cost effectiveness numbers are negative. Since Regulatory Alternative IV is the only one with a positive net cost, comparisons of cost effectiveness in the normal sense are meaningless. The highest cost of VOC control under Regulatory Alternative IV is for model unit A. Although

TABLE 8-7. LABOR-HOUR REQUIREMENTS FOR INITIAL LEAK REPAIR

	Number of components per model unit			Regulatory alternative II							Regulatory alternative III							Regulatory alternative IV						
				Estimated number of initial leaks[b]			Repair time, hrs	Labor-hours required			Estimated number of initial leaks[b]			Repair time, hrs	Labor-hours required			Estimated number of initial leaks[b]			Repair time, hrs	Labor-hours required		
Source type	A	B	C	A	B	C		A	B	C	A	B	C		A	B	C	A	B	C		A	B	C
Pumps (light liquid)																								
Single mechanical seal	5	19	60	2	5	14	80[c]	160	400	1120	2	5	14	80[c]	160	400	1120	0[e]	0[e]	0[e]	80[c]	0	0	0
Dual mechanical seals	3	10	31	1	3	8	80[c]	80	240	640	1	3	8	80[c]	80	240	640	0[e]	0[e]	0[e]	80[c]	0	0	0
Valves (in-line)																								
Gas	90	365	1117	9	37	112	1.13[d]	10	42	127	9	37	112	1.13[d]	10	42	127	9	37	112	1.13[d]	10	42	127
Light liquid	84	335	1037	11	41	125	1.13[d]	12	46	141	11	41	125	1.13[d]	12	46	141	11	41	125	1.13[d]	12	46	141
Safety/relief valves[a] (gas service)	11	42	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0[e]	0[e]	0[e]	0	0	0	0
Valves on open-ended lines[f]																								
Gas	9	37	115	1	4	12	1.13[d]	1	5	14	1	4	12	1.13[d]	1	5	14	1	4	12	1.13[d]	1	5	14
Light liquid	47	189	581	6	23	70	1.13[d]	7	26	79	6	23	70	1.13[d]	7	26	79	6	23	70	1.13[d]	7	26	79
Compressor seals	1	2	8	1	1	3	40[c]	40	40	120	1	1	3	40[c]	40	40	120	0[e]	0[e]	0[e]	40[c]	0	0	0

[a] It is assumed that these leaks are corrected by routine maintenance at no additional labor requirements. Ref. 58.

[b] Based on the percent of sources leaking at ≥ 10,000 ppm. From Table 4-2.

[c] Ref. 59.

[d] Weighted average based on 75 percent of the leaks repaired on-line, requiring 0.17 hours per repair, and on 25 percent of the leaks repaired off-line, requiring 4 hours per repair. Ref. 60.

[e] No maintenance required because equipment specification eliminates leak potential.

[f] The estimated number of initial leaks for open-ended valves is based on the same percentage of sources used for in-line valves. This represents leaks occurring through the stem and gland of the open-ended valve. Leaks through the valve seat are eliminated by adding caps for Regulatory Alternatives II, III, IV.

TABLE 8-8. RECOVERY CREDITS.

Regulatory alternative	Model unit A			Model unit B			Model unit C		
	VOC emissions, Mg/yr	Emission reduction from uncontrolled, Mg/yr	Recovered[a] product value, $/yr	VOC emissions, Mg/yr	Emission reduction from uncontrolled, Mg/yr	Recovered[a] product value, $/yr	VOC emissions, Mg/yr	Emission reduction from uncontrolled, Mg/yr	Recovered[a] product value, $/yr
I	67.2	--	--	257	--	--	800	--	--
II	24.5	42.7	15,400	93.7	163	58,800	293	507	182,000
III	20.8	46.4	16,700	79.8	177	63,800	249	551	198,000
IV	8.46	58.7	21,100	34.3	223	80,200	106	694	250,000

[a] Last quarter 1978 dollars. Based on an average price of $360/Mg. Ref. 61.

TABLE 8-9. ANNUALIZED CONTROL COST ESTIMATES FOR MODEL UNIT A (thousands ~~of last~~ quarter 1978 dollars).

Cost item	Regulatory alternative I	II	III	IV
Annualized capital charges				
1. Control equipment				
a. Instrument		1.96	1.96	1.96
b. Caps		.763	.763	.763
c. Dual seals[a]				
• Seals				0.974
• Installation				.196
d. Barrier fluid system[b]				1.22
e. Vents - pumps and compressors				5.32
f. Rupture disks				
• Disks				1.24
• Holders, etc.				2.74
g. Closed loop sampling				1.96
2. Initial leak repair		1.06	1.06	0.10
Operating costs				
1. Maintenance charges				
a. Instrument		2.70	2.70	2.70
b. Caps		.234	.234	.234
c. Dual seals				0.144
d. Barrier fluid system				.375
e. Vents - pumps and compressors				1.63
f. Rupture disks				.950
g. Closed loop sampling				0.60
2. Miscellaneous (taxes, insurance, administration)				
a. Instrument		.340	.340	.340
b. Caps		.187	.187	.187
c. Dual seals				.115
d. Barrier fluid system				0.30
e. Vents - pumps and compressors				1.31
f. Rupture disks				.758
g. Closed loop sampling				.48
3. Labor				
a. Monitoring labor		0.54	2.26	1.43
b. Leak repair labor		3.17	3.30	0.304
c. Administrative and support[c]		1.51	2.22	0.692
Total before credit	0.0	12.1	15.0	29.0
Recovery credits[d]	0.0	15.4	16.7	21.1
Net annualized cost[e]	0.0	(-3.3)	(-1.7)	7.9

[a] Cost is for back-to-back arrangement.

[b] Pressurized system.

[c] Based on 40 percent of monitoring plus leak repair labor. Ref. 62.

[d] Based on an average price of $360/Mg. Ref. 63.

[e] (-xx) ⟹ net credit

TABLE 8-10. ANNUALIZED CONTROL COST ESTIMATES FOR MODEL UNIT B (thousands of last quarter 1978 dollars)

Cost item	Regulatory alternative			
	I	II	III	IV
Annualized capital charges				
1. Control equipment				
a. Instrument		1.96	1.96	1.96
b. Caps		3.05	3.05	3.05
c. **Dual seals**[a]				
· Seals				3.69
· Installation				.743
d. **Barrier fluid system**[b]				4.65
e. Vents - pumps and compressors				17.6
f. Rupture disks				
· Disks				4.75
· Holders, etc.				10.5
g. Closed loop sampling				7.79
2. Initial leak repair		2.73	2.73	0.41
Operating costs				
1. Maintenance charges				
a. Instrument		2.7	2.7	2.7
b. Caps		.935	.935	.935
c. **Dual seals**				.546
d. **Barrier fluid system**				1.42
e. Vents - pumps and compressors				5.39
f. Rupture disks				3.63
g. Closed loop sampling				2.39
2. Miscellaneous (taxes, insurance, administration)				
a. Instrument		0.34	0.34	0.34
b. Caps		.748	.748	.748
c. **Dual seals**				.437
d. **Barrier fluid system**				1.14
e. Vents - pumps and compressors				4.31
f. Rupture disks				2.90
g. Closed loop sampling				1.91
3. Labor				
a. Monitoring labor		2.04	8.75	5.74
b. Leak repair labor		3.54	7.69	1.09
c. Administrative and support[c]		2.23	6.58	2.73
Total before credit	0.0	20.3	35.5	93.5
Recovery credits[d]	0.0	58.8	63.8	80.2
Net annualized cost[e]	0.0	(-38.5)	(-28.3)	13.3

[a] Cost is for back-to-back arrangement.

[b] Pressurized system.

[c] See footnote from preceeding Table 8-9, Ref. 64.

[d] Based on an average price of $360/Mg. Ref. 65

[e] (-xx) ⟹ net credit

TABLE 8-11. ANNUALIZED CONTROL COST ESTIMATES FOR MODEL UNIT C (thousands of last quarter 1978 dollars)

Cost item	Regulatory alternative			
	I	II	III	IV
Annualized capital charges				
1. Control equipment				
a. Instrument		1.96	1.96	1.96
b. Caps		9.37	9.37	9.37
c. **Dual seals**[a]				
· Seals				11.7
· Installation				2.35
d. **Barrier fluid system**[b]				14.7
e. Vents - pumps and compressors				56.9
f. Rupture disks				
· Disks				14.7
· Holders, etc.				32.4
g. Closed loop sampling				24.0
2. Initial leak repair		7.67	7.67	1.23
Operating Costs				
1. Maintenance charges				
a. Instrument		2.70	2.70	2.70
b. Caps		2.88	2.88	2.88
c. **Dual seals**				1.72
d. **Barrier fluid system**				4.50
e. Vents - pumps and compressors				17.5
f. Rupture disks				11.2
g. Closed loop sampling				7.35
2. Miscellaneous (taxes, insurance, administration)				
a. Instrument		0.340	0.340	0.340
b. Caps		2.30	2.30	2.30
c. **Dual seals**				1.38
d. **Barrier fluid system**				3.60
e. Vents - pumps and compressors				14.0
f. Rupture disks				8.98
g. Closed loop sampling				5.88
3. Labor				
a. Monitoring labor		6.33	27.14	17.7
b. Leak repair labor		8.71	21.3	3.25
c. **Administrative and support**[c]		6.02	19.4	8.38
Total before credit	0.0	48.3	95.1	283.
Recovery credits[d]	0.0	182.	198.	250.
Net annualized cost[e]	0.0	(-134.)	(-103.)	33.0

[a] **Cost is for back-to-back arrangement.**

[b] **Pressurized system.**

[c] **Based on 40 percent of monitoring plus leak repair labor. Ref. 66.**

[d] **Based on an average price of $360/Mg. Ref. 67.**

[e] **(-xx) ==>net credit**

TABLE 8-12. COST EFFECTIVENESS FOR MODEL UNITS
(last quarter 1978 dollars)

Regulatory alternative	Model unit A[a]				Model unit B[b]				Model unit C[c]			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
Total capital cost ($1000)	0.0	13.2	13.2	87.1	0.0	27.2	27.2	295	0.0	66.0	66.0	911
Total annualized cost ($1000)	0.0	12.1	15.0	29.0	0.0	20.3	35.5	93.5	0.0	48.3	95.1	283
Total annual recovery credit ($1000)	0.0	15.4	16.7	21.1	0.0	58.8	63.8	80.2	0.0	182.	198.	250.
Net annualized cost ($1000)[d]	0.0	(-3.3)	(-1.7)	7.9	0.0	(-38.5)	(-38.3)	13.3	0.0	(-134.)	(-103.)	33.0
Total VOC reduction (Mg/yr)	0.0	42.7	46.4	58.7	0.0	163	177	223	0.0	507	551	694
Cost effectiveness (annual $/Mg VOC)[d]	-	(-77.3)	(-36.6)	135.	-	(-236.)	(-160.)	59.6	-	(-264.)	(-187.)	47.6

[a] 52 percent of the units in the SOCMI are similar to Model Unit A. Ref. 68.

[b] 33 percent of the units in the SOCMI are similar to Model Unit B. Ref. 69.

[c] 15 percent of the units in the SOCMI are similar to Model Unit C. Ref. 70.

[d] (-xx) = Control method net credit

this cost ($135/Mg) is much larger than the cost for model unit C ($48/Mg), the net annualized cost for model unit A is only $7900. This amount is insignificant compared to the annual operating cost of the process unit itself.

8.1.3 Modified/Reconstructed Facilities

8.1.3.1 Capital Costs. The bases for determining the capital costs for modified/reconstructed facilities are presented in Table 8-1. The capital costs for these units are the same under Regulatory Alternatives II and III as are those for new units. There are no costs associated with Alternative I. The capital costs for the monitoring instruments, the caps for open-ended lines, the barrier fluid systems, the vents for degassing reservoirs, and the closed loop sampling connections are also the same as for new units.

The estimated cost of retrofitting dual mechanicals seals for single seal pumps was estimated at $850 per pump. This figure includes $560 for a new back-to-back dual mechanical seal plus $290 labor for field installation.

Rupture disks for relief valves, required under Regulatory Alternative IV, were estimated to cost $2970 per relief valve. The original relief valve must be replaced with a larger relief valve. The cost for a new valve was included in the cost estimates. Credit for the removed valve was not included.

The total capital cost estimates for modified/reconstructed facilities are presented in Table 8-13. As noted above, the costs associated with Regulatory Alternatives I, II, and III are the same as for new units.

8.1.3.2 Annualized Costs. The annualized control costs for modified/reconstructed units, presented in Table 8-14, are derived from the same basis as new units (see Table 8-2). The only changes from new unit costs occur under Regulatory Alternative IV because of the increased capital costs for dual mechanical seals and rupture disks. The recovered product credits for the modified/reconstructed units are the same as for the new model units.

TABLE 8-13. CAPITAL COST ESTIMATES FOR MODIFIED/ RECONSTRUCTED FACILITIES
(thousands of last quarter 1978 dollars)

	Regulatory alternative IV[b]		
	Model unit		
Capital cost item[a]	A	B	C
1. Monitoring instrument	8.5	8.5	8.5
2. Caps for open-ended lines	4.68	18.7	57.5
3. Dual mechanical seals[c]			
• Seals	2.8	10.6	33.6
• Installation	1.45	5.51	17.4
4. Barrier fluid systems for double mechanical seals[d]	7.50	28.5	90.0
5. Vents for compressor degassing reservoirs	6.53	13.1	52.2
6. Vents for pump degassing reservoirs	26.1	94.7	297
7. Rupture disks for relief valves			
• Disks	2.14	8.19	25.4
• Holders, block valves, installation	16.8	64.4	199
• Replacement relief valve and installation	15.2	58.0	179
8. Closed loop sampling connections	12.0	47.8	147
Total	104	358	1107

[a] From Tables 6-1 and 8-1.

[b] For Regulatory Alternatives I, II, III the capital costs for modified/ reconstructed facilities are the same as for new units (Table 8-2).

[c] Cost is for back-to-back arrangement.

[d] Pressurized system.

TABLE 8-14. ANNUALIZED CONTROL COST ESTIMATES FOR MODIFIED/RECONSTRUCTED MODEL UNITS UNDER REGULATORY ALTERNATIVE IV[a] (thousands of last quarter 1978 dollars)

Cost item	Model unit A[b]	Model unit B[c]	Model unit C[d]
Annualized capital charges			
1. Control equipment			
a. Instrument	1.96	1.96	1.96
b. Caps	.763	3.05	9.37
c. Dual seals[e]			
· Seals	1.62	6.15	19.5
· Installation	.236	0.898	2.84
d. Barrier fluid system[f]	1.22	4.65	14.7
e. Vents for pumps and compressors	5.32	17.6	56.9
f. Rupture disks			
· Disks	1.24	4.75	14.7
· Holders, etc.	2.74	10.5	32.4
· Relief valves	2.48	9.45	29.2
g. Closed loop sampling	1.96	7.79	24.0
2. Initial leak repair	0.10	0.41	1.23
Operating costs			
1. Maintenance charges			
a. Instrument	2.70	2.70	2.70
b. Caps	.234	.935	2.88
c. Dual seals	0.213	0.806	2.55
d. Barrier fluid system	.375	1.42	4.50
e. Vents for pumps and compressors	1.63	5.39	17.5
f. Rupture disks	1.71	6.53	20.2
g. Closed loop sampling	.60	2.39	7.35
2. Miscellaneous (taxes, insurance, administration)			
a. Instrument	.340	.340	.340
b. Caps	.187	.748	2.30
c. Dual seals	0.170	.644	2.04
d. Barrier fluid system	0.30	1.14	3.60
e. Vents for pumps and compressors	1.31	4.31	14.0
f. Rupture disks	1.37	5.22	16.2
g. Closed loop sampling	.480	1.91	5.88
3. Labor			
a. Monitoring labor	1.43	5.74	17.7
b. Leak repair labor	0.304	1.09	3.25
c. Administrative and support[g]	0.692	2.73	8.38
Total before credit	33.7	111.	338.
Recovery credits[h]	21.1	80.2	250.
Net annualized cost	12.6	30.8	88.
Total VOC reduction (Mg/yr)	58.7	223.	694
Cost effectiveness ($/Mg VOC)	215.	138.	127.

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[a] For Regulatory Alternatives I, II, III, the annualized control costs and cost effectiveness for modified/reconstructed facilities are the same as for new units (Tables 8-7, 8-8, 8-9).

[b] 52 percent of existing units are similar to Model Unit A. Ref. 71

[c] 33 percent of existing units are similar to Model Unit B. Ref. 72.

[d] 15 percent of existing units are similar to Model Unit C. Ref. 73.

[e] Cost is for back-to-back arrangement.

[f] Pressurized system

[g] Based on 40 percent monitoring plus leak repair labor. Ref. 74.

[h] Based on an average price of $360/Mg. Ref. 75.

8.1.3.3 Cost Effectiveness. The cost effectiveness figures for modified/reconstructed facilities are also shown in Table 8-14. The cost effectiveness under Regulatory Alternatives I, II, and III is the same as for the new model units. The cost effectiveness under Regulatory Alternative IV is a net cost of $215 per Mg for model unit A, $138 for model unit B, and $127 for model unit C.

8.1.4 Projected Cost Impacts

The regulatory alternatives are assumed to go into effect by 1981, using 1980 as the base year. The industry is estimated to grow at a rate of 5.9 percent.[76] SOCMI facilities are estimated to be replaced at a rate based on a 20-year equipment life (see Appendix E). The estimated numbers of projected new units are presented in Tables 7-5, 7-6, and 7-7. The estimated costs to the industry for the years 1981 through 1985 are presented in Tables 8-15 through 8-17. Capital costs shown are only for units which begin operation in the indicated year. All other costs shown are for all units subject to NSPS in the indicated year.

8.2 OTHER COST CONSIDERATIONS

Environmental, safety, and health statutes which are applicable to SOCMI plants are listed in Table 8-18. The provisions, requirements, and regulations listed are those which may cause an outlay of funds by an organic chemical manufacturer.

Specific costs of each of these provisions or requirements to the industry defined as SOCMI were unavailable. Total costs to SOCMI for complying with environmental, safety and health standards were also unavailable.

The entire chemical industry is planning to spend an estimated $639 million on pollution control in 1979 according to a McGraw-Hill Survey.[77] Although this is a sizeable sum of money, the industry has enjoyed three decades of rapid growth and high profits. The economic health of the industry is better than that of many other industries.[78] The substantial pollution problems encountered in the industry and the large expenditures

TABLE 8-15. NATIONWIDE COSTS FOR THE INDUSTRY UNDER REGULATORY ALTERNATIVE II
(last quarter 1978 dollars)

Cost item[a]	1981	1982	1983	1984	1985
Total capital cost ($1000)[b]	3,800	4,040	4,280	4,490	4,790
Total annualized cost ($1000)[c]	2,990	6,160	9,530	13,100	16,800
Total annual recovery credit ($1000)	8,070	16,700	25,800	35,300	45,500
Net annualized cost ($1000)[d]	(-5,080)	(-10,500)	(-16,300)	(-22,200)	(-28,700)

[a] From Tables 8-2, 8-9, 8-10, 8-11.

[b] Capital costs for model units which begin operation in the years shown.

[c] Annualized costs for all model units subject to NSPS in the years shown.

[d] (-xx) ➡ net credit

TABLE 8-16. NATIONWIDE COSTS FOR THE INDUSTRY UNDER REGULATORY ALTERNATIVE III
(last quarter 1978 dollars)

Cost item[a]	1981	1982	1983	1984	1985
Total capital cost ($1000)[b]	3,800	4,040	4,280	4,490	4,790
Total annualized cost ($1000)[c]	4,990	10,300	15,900	21,800	28,100
Total annual recovery credit ($1000)	8,770	18,100	28,000	38,400	49,400
Net annualized cost ($1000)[d]	(-3,780)	(-7,800)	(-12,100)	(-16,600)	(-21,300)

[a] From Tables 7-6, 8-7, 8-8, 8-9.

[b] Capital costs for model units which begin operation in the years shown.

[c] Annualized costs for all model units subject to NSPS in the years shown.

[d] (-xx) ⇒ net credit

TABLE 8-17. NATIONWIDE COSTS FOR THE INDUSTRY UNDER REGULATORY ALTERNATIVE IV (last quarter 1978 dollars)

Cost item[a]	1981	1982	1983	1984	1985
Total capital cost ($1000)[b]	41,200	44,000	46,500	48,700	51,900
Total annualized cost ($1000)[c]	13,000	27,000	41,700	57,100	73,500
Total annual recovery credit ($1000)	11,100	22,900	35,400	48,500	62,400
Net annualized cost ($1000)[d]	1,900	4,100	6,300	8,600	11,100

[a] From Tables 7-6, 8-7, 8-8, 8-9.

[b] Capital costs for model units which begin operation in the years shown.

[c] Annualized costs for all model units subject to NSPS in the years shown.

[d] (-xx) ➡ net credit

TABLE 8-18. STATUTES THAT MAY BE APPLICABLE TO SOCMI

Statute	Applicable provision, regulation or requirement of statute	Approximate cost incurred due to enactment of statute	
		Model unit	Industry
Clean Air Act and Amendments	· State implementation plans · National emission standards for hazardous air pollutants Benzene fugitive emissions · New source performance standards Air oxidation Volatile organic liquid storage · PSD construction permits · Non-attainment construction permits	Total	$249 million[a]
Clean Water Act (Federal Water Pollution Act)	· Discharge permits · Effluent limitations guidelines · New source performance standards · Control of oil spills and discharges · Pretreatment requirements · Monitoring and reporting · Permitting of industrial projects that impinge on wetlands or public waters · Environmental impact statements	Total	$414 million[b]
Resource Conservation and Recovery Act	· Permits for treatment, storage, and disposal of hazardous wastes · Establishes system to track hazardous wastes · Establishes recordkeeping, reporting, labelling and monitoring system for hazardous wastes · Superfund	Total	$200 million[c] Superfund-less than 2% of profits or $200 million maximum annual rate on petrochemical feedstock[d] Production costs for the industry are expected to increase by an average of 0.6% and a maximum of 5%.[e]
Toxic Substances Control Act	· Premanufacture notification · Labelling, recordkeeping · Reporting requirements · Toxicity testing	Total	$100-200 million per year[f] Preinventory notification cost: $1200-1500 per chemical[g]

(Continued)

TABLE 8-18. (Cont.)

Statute	Applicable provision, regulation or requirement of statute	Approximate cost incurred due to enactment of statute: Model unit	Approximate cost incurred due to enactment of statute: Industry
Occupational Safety and Health Act	· Walking-working surface standards · Means of egress standards · Occupational health and environmental control standards · Hazardous material standards · Personal protective equipment standards · General environmental control standards · Medical and first aid standards · Fire protection standards · Compressed gas and compressed air equipment · Welding, brazing, and cutting standards	Total	$220/year per worker[h]
Coastal Zone Management Act	· States may veto federal permits for plants to be sited in coastal zone		
Power Plant and Industrial Fuel Use Act	· Prohibits new, major, industrial powerplants which utilize fuel oil or natural gas		
National Environmental Policy Act	· Requires environmental impact statements		
Safe Drinking Water Act	· Requires underground injection control permits		
Marine Sanctuary Act	· Ocean dumping permits · Recordkeeping and reporting		

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[a] Expenditure, by entire chemical industry, on air pollution control; SOCMI's portion of expenditure not delineated. (Ref. 80.)

[b] Expenditure, by entire chemical industry, on water pollution control; SOCMI's portion of expenditure not delineated. (Ref. 81

[c] Cost reflects entire organic industry; SOCMI's cost not delineated. (Ref. 82).

[d] Cost reflects entire organic industry; SOCMI's cost not delineated. (Ref. 83,84).

[e] Cost reflects entire organic industry; SOCMI's cost not delineated. (Ref. 85).

[f] Cost incurred by entire chemical industry; SOCMI's portion of expenditure not delineated. (Ref. 86).

[g] Cost incurred by entire chemical industry; SOCMI's portion of expenditure not delineated. (Ref. 87).

[h] Cost incurred by entire chemical industry; SOCMI's portion of expenditure not delineated. (Ref. 88).

necessary for their solution are expected to affect the smaller firms more adversely than the larger firms. However, few plant closings are expected due solely to costs of compliance with standards and regulations.[79]

The costs incurred by SOCMI in complying with all health, safety, and environmental requirements are not expected to prevent compliance with the proposed NSPS for fugitive emissions.

8.3 REFERENCES

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8. Reference 2, p. IV-3.

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10. Reference 2, p. IV-3.

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9. ECONOMIC ANALYSIS

9.1 INDUSTRY PROFILE

9.1.1 Introduction

The synthetic organic chemicals manufacturing industry (SOCMI) has been defined as the producers of synthetic organic chemicals, listed in Appendix F. This profile gives a general qualitative description of the industry, supported by quantitative information wherever possible. Because SOCMI does not directly correspond to industrial classifications used for reporting information by secondary data sources, a weighting technique was used to develop industry statistics (see Appendix E1).

Synthetic organic chemicals (SOCs) are substances containing at least carbon and hydrogen. They exhibit three basic molecular structures: aliphatic or acyclic, cyclic, and combinations of aliphatic and cyclic. Acyclic compounds are composed of groups of atoms arranged in a straight chain. Examples are alcohols, ethers, ketones, and carbohydrates. Cyclic compounds have the atoms of their component elements arranged in the form of a closed ring. Examples include aromatic hydrocarbons, napthenes, and thiazoles. Certain amino acids and terpene hydrocarbons represents combinations of cyclic and aliphatic molecular structures.[1]

SOCMI chemicals may be used as primary feedstocks, chemical intermediates, or end use chemicals. Primary feedstocks are produced from crude raw materials and used in the manufacture of other chemicals. Chemical intermediates are the product of primary feedstocks and are also used to produce other chemicals. End use chemicals are products of chemical intermediates and/or primary feedstocks and are used either as final goods or as inputs to production processes outside the chemical industry. Many synthetic organic chemicals are used in more than one of these categories. Figure 3.1 illustrates the general relationships among the various organic chemicals.

Detailed flow charts identifying inputs and product use for many of the SOCMI chemicals have been presented elsewhere.[2]

9.1.2 Production Processes and Capacities

Most of the SOCMI chemicals produced in the United States are derived from crude petroleum and natural gas. Oil, shale, coal, and biomass (non-prehistoric plant tissue) are also sources of primary feedstocks.[3] A wide variety of processes are used to manufacture the **synthetic organic** chemicals included in the definition of SOCMI. Frequently individual chemicals can be manufactured in several different ways. Consequently, as relative prices change, chemical producers may alter the mix of primary feedstocks used to produce SOCs.

After chemical feedstocks are manufactured from petroleum, natural gas, and other raw materials, they are processed into chemical intermediates and end use chemicals. Some of the chemicals included in SOCMI are the product of a simple distillation process, while others are produced from a series of cracking processes.

In 1976 Organic Chemical Producers Data Base[4] reports 1,270 units producing SOCMI chemicals in the United States.* Table 9-1 presents a distribution of those units and estimated capacity by state. New Jersey, Texas, and California have the largest number of units producing SOCMI chemicals. Texas and Louisiana have the largest total production capacities. These states are major producers because of their petroleum deposits and good sea port facilities. Table 9-2 presents a geographical distribution of units by reported capacity. Approximately 12 percent of these units produce fewer than 5,000 Mg. Another 12 percent of the units have production capacities in excess of 500,000 Mg. Seventy-five of these large facilities are located in the southwest central region of the United States, which includes Texas and Louisiana. Table 9-3 presents the total reported capacity for each region by unit size.

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*The 1976 version of the Organic Chemical Producers Data Base is used because it was the most recent version available.

TABLE 9-1. ESTIMATED ANNUAL PRODUCTION CAPACITY BY STATE, 1976[a]

State	Number of units	Percentage of units reporting capacity	Estimated total capacity,[a] (10^3 Mg)
Total	1,270	40	319,835
Alabama	25	52	5,174
Alaska	2	50	399
Arizona	1	00	91
Arkansas	12	33	1,982
California	120	23	19,650
Colorado	5	20	644
Connecticut	18	26	2,765
Delaware	14	50	2,031
Florida	14	43	3,257
Georgia	20	30	3,459
Hawaii	1	00	91
Idaho	2	50	97
Illinois	85	31	16,517
Indiana	31	26	3,551
Iowa	11	64	1,698
Kansas	1	00	390
Kentucky	27	56	6,062
Louisiana	54	74	31,810
Maine	1	00	390
Maryland	17	35	2,160
Massachusetts	27	48	4,835
Michigan	28	25	9,735
Minnesota	6	17	574
Mississippi	15	47	1,999
Missouri	16	37	4,072
Montana	1	100	222
Nebraska	4	100	103
Nevada	2	50	122
New Hampshire	5	40	483
New Jersey	131	24	28,070
New York	52	19	10,586
North Carolina	50	38	7,283
Ohio	88	26	14,576
Oklahoma	9	78	702
Oregon	17	53	3,838
Pennsylvania	75	27	14,634
Puerto Rico	13	85	7,259
Rhode Island	8	00	815
South Carolina	27	48	3,875
Tennessee	24	46	6,809
Texas	126	76	77,189
Utah	4	25	628
Vermont	1	100	2
Virgin Islands	2	100	643
Virginia	22	68	3,581
Washington	13	46	2,502
West Virginia	24	63	9,242
Wisconsin	18	22	3,514
Wyoming	1	100	24

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[a] Capacities were estimated by calculating the mean of reported unit capacity for each chemical. This was substituted for any missing values of unit capacity for each chemical. If no units reported capacity for a chemical, then the mean of all chemicals was substituted for the missing value. Estimated capacity represents the sum of reported capacities, means of reported capacity for some specific chemicals, and industry mean reported capacity for other chemicals.

TABLE 9-2. DISTRIBUTION OF UNITS BY UNIT CAPACITY AND REGION, 1976[4]

Region	Number of units										
	Unit capacity ranges (10^3 Mg)								Units reporting capacity	Units not reporting capacity	Total units
	0-5	5-10	10-25	25-50	50-100	100-250	250-500	500+			
North east	17	5	12	16	17	10	5	1	83	235	318
New England	7	0	4	5	4	0	1	0	21	39	60
Mid-Atlantic	10	5	8	11	13	10	4	1	62	196	258
North central	16	5	13	13	13	17	6	3	86	202	288
East	13	3	10	9	9	16	6	2	68	182	250
West	3	2	3	4	4	1	0	1	18	20	38
South	23	7	34	38	44	50	34	50	280	200	480
East south central	2	3	12	8	5	9	3	4	46	45	91
West south central	4	3	10	18	20	24	24	44	147	54	201
South Atlantic	17	1	12	12	19	17	7	2	87	101	188
West	3	2	17	12	5	8	3	0	50	119	169
Mountain	0	1	3	2	0	0	0	0	6	10	16
Pacific	3	1	14	10	5	8	3	0	44	109	153
Total	59	19	76	79	79	85	48	54	499	756	1,255

TABLE 9-3. DISTRIBUTION OF INDUSTRY CAPACITY BY UNIT CAPACITY AND REGION, 1976[4]

	Industry capacity								
	Unit capacity (10^3 Mg)								
Region	0-5	5-10	10-25	25-50	50-100	100-250	150-500	≥500	Total
North east	37.7	43.1	199.2	548.4	1,177.6	1,392.6	1,811.2	742.5	5,952
New England	19.1	--	70.8	176.9	263.1	--	299.4	--	829
Mid-Atlantic	18.6	43.1	128.4	371.5	914.5	1,392.6	1,511.8	742.5	5,123
North central	42.2	38.8	205.9	478.1	953.0	2,544.7	2,024.9	2,430.8	8,718
East	38.1	22.5	142.4	350.2	664.1	2,406.8	2,024.9	1,906.9	7,556
West	4.1	16.3	63.5	127.9	288.9	137.9	--	523.9	1,163
South	62.9	58.8	605.6	1,442.0	3,236.1	8,369.	11,910.9	67,600.5	93,287
East south central	1.3	23.6	204.6	299.4	316.2	1,494.6	984.5	3,132.6	6,457
West south central	12.2	28.8	194.6	710.8	1,532.3	4,411.7	8,596.6	63,197.8	78,685
South Atlantic	49.4	6.4	206.4	431.8	1,387.6	2,463.5	2,329.8	1,270.1	8,145
West	5.0	13.2	298.4	477.2	342.5	1,055.1	1,024.2	--	3,216
Mountain	--	6.4	48.5	72.6	--	--	--	--	127
Pacific	5.0	6.8	249.9	404.6	342.5	1,055.1	1,024.2	--	3,088
Caribbean	--	--	--	109.8	72.6	--	1,324.1	5,659.1	7,166
Total	147.8	153.9	1,309.1	3,055.5	5,781.8	13,362.2	18,095.3	76,432.9	118,339

9.1.3 Production and Sales

Production and sales data for the SOCMI are presented in Table 9-4. The production of SOCMI chemicals increased from 58,050 Gq in 1968 to 84,530 Gg in 1978, at an average annual growth rate of approximately 3.5 percent. However, output levels have fluctuated widely since 1974. The effects of the oil embargo, the increase in energy and feedstock prices, and the sharply reduced demand resulting from a major economic recession caused the industry to cut back production by 13.2 percent in 1975. In 1976 output rose only slightly, but, in 1977, as real prices for energy and feedstocks fell, the economy recovered, and the need to increase inventories became urgent, production increased by 50.4 percent. In 1978 energy and feedstock prices began to increase again and the need to replenish inventories disappeared. Output declined that year by 28.6 percent. Nevertheless, production 1978 was greater than in 1974, suggesting that the industry may have substantially adjusted to the shocks experienced in 1974 and 1975.

Sales and production trends were virtually identical over the period 1967-1968*. The two variables are likely to remain highly correlated in the future, because the industry's feedstock requirements are closely tied to its production levels. The absolute level of sales was much lower than the level of production (45.6 percent of production) over the period 1967 to 1978. The difference between output and sales represents captive consumption, indicating that the indsutry has a relatively high degree of vertical integration.

9.1.4 Resource Use

Estimates of employment, assets, cost of materials and energy used in SOCMI from 1972 to 1976 are presented in Table 9-5. In general, resource use increased with production. Total industry employment, including administrative, clerical, marketing and service employees as well as production workers, increased 5 percent from 1972 to 1976. Employment of production workers increased 4.1 percent during this period, although the number of production workers declined during the adjustment period following the 1973-74 oil

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*The estimated correlation coefficient for the two variables over this period is 0.97.

TABLE 9-4. ANNUAL PRODUCTION AND SALES OF SYNTHETIC ORGANIC CHEMICALS[5]

Year	Production[a] (Gg)	Sales volume[a] (Gg)	Sales value[a] ($$10^6$)	Average unit value[a] ($/kg)
1967	51,380	23,440	3,085.55	0.13
1968	58,050	26,960	3,411.91	0.13
1969	65,210	30,360	3,590.07	0.11
1970	68,140	32,090	3,702.20	0.12
1971	69,020	33,020	3,724.03	0.11
1972	76,740	36,930	4,173.97	0.11
1973	81,220	39,420	4,991.53	0.13
1974	83,720	38,450	9,357.99	0.24
1975	72,660	32,920	8,411.34	0.26
1976	76,030	32,520	10,187.76	0.29
1977	114,320	49,470	15,317.72	0.31
1978	84,530	35,310	12,951.16	0.36

[a] See Appendix E1 for a discussion of the methodology used to compute these data.

TABLE 9-5. SOCMI RESOURCE USE[6]

Year	Total employment (10^3)	Production workers (10^3)	Total assets ($\$10^6$)	Cost of materials ($\$10^6$)	Energy purchased for heat and power (10^9 joules)
1972	130.6	83.2	12,287.8	5,338.5	1,220.1[a]
1973	132.3	85.1	13,048.3	6,311.8	1,286.6[a]
1974	130.3	84.0	13,919.5	10,388	1,322.7[a]
1975	132.7	82.7	16,198.2	11,569	1,154.4[a]
1976	137.1	86.6	18,788.3	14,503.1	1,202.4

[a] These data were estimated by multiplying the 1976 estimate of energy use by the ratio of production in each of the previous years to 1976 production levels. Thus, for example, energy use in 1972 was estimated by multiplying energy use in 1976 by the ratio of production in 1972 to production in 1976.

embargo. Cost of materials increased substantially during the 1972-1976 period; however, much of this increase can be attributed to rapidly increasing prices of crude petroleum. Consumption of energy for heat and power has fluctuated, resulting in an overall decrease of about 1 percent from 1972 to 1976. Value of assets increased each year from 1972 to 1976. The total increase during that period was approximately 53 percent, much of which can be accounted for by changes in the value of buildings and equipment. The stock of physical assets increased at a much slower rate.

9.1.5 Consumption

The chemicals in SOCMI have a wide variety of end uses as fuels, solvents, pesticides, and pigments, and as feedstocks for the production of plastics, synthetic fibers and textiles, soaps and detergents, rubber products, medicines and fertilizers. It is not possible to estimate consistently apparent consumption, because import and export data presented in Table 9-6 for SOCMI are not compatible with the production and sales data presented in Table 9-4. However, it is probable that historical consumption trends have been similar to historical production and sales trends. Certainly, over the period 1967-1978, consumption increased, although since 1974, if the sales data presented in Table 9-4 can be regarded as an indicator of consumption, consumption exhibited wide year-to-year variations for the reasons discussed in Section 9.1.3.

9.1.6 Prices

The general level of prices for SOCMI chemicals more than tripled between 1967 and 1978. Most of the increase occurred after 1973. From 1967 to 1973, the average unit price of SOCMI chemicals remained close to \$0.12/kg. Following the 1973-1976 adjustments in oil prices, average prices in SOCMI doubled, rising to \$0.24/kg. After that time average unit prices increased at a rate of approximately 11 percent annually, to a price of \$0.36/kg in 1978. It is important to realize that these are average prices per unit of all SOCMI chemicals. In 1976, prices for individual chemicals ranged from \$0.11/kg for formaldehyde to \$4.30/kg for benzophenone. Changes in the unit price for individual chemicals may vary substantially from the changes in average prices. Table 9-4 presents annual statistics of production, sales volume, sales value and average unit value for the industry. The data are weighted using the procedures described in Appendix E1 to reflect the behavior of the industry as accurately as possible.

9.1.7 International Trade

Chemical imports were first made subject to tariffs at the beginning of the 20th century. The tariffs were initiated to protect the infant chemical industry from foreign competition. Since 1936, tariffs have been progressively lowered on chemical products.[7] The U.S. International Trade Commission reports 824 benzenoid intermediates on which tariffs are collected. Of these, 179 are assessed duties competitively using import prices as the basis for tariffs. Another 430 of these products are classified noncompetitive, with tariffs based on U.S. domestic prices. The competitive status of 15 products is not available.[8] The remainder are not tariffed.

Accurate data concerning imports and exports of SOCMI chemicals are not available. The most reasonable approximation of trade statistics for SOCMI are provided by the U.S. International Trade Comission.[5] Annual value of imports and exports for the period 1966-1967 is presented in Table 9-6. In each of these years, U.S. exports exceeded U.S. imports of industrial organic chemicals. Table 9-7 presents imports, exports and trade balance of industrial organic chemicals in 1976 and 1977 between the United States and its principal trading partners. These countries include West Germany, Italy, the United Kingdom, Switzerland, France, Belgium, the Netherlands, Canada, Japan, Mexico, Brazil, and Argentina. In 1977 the U.S. experienced a deficit in its balance of trade in chemicals with West Germany, Japan, Italy, the United Kingdom, Switzerland and France. Itexperienced a surplus in its balance of trade in chemicals with Belgium, Canada, the Netherlands, Mexico, Argentina and Brazil. Table 9-8 presents the value of imports for consumption from principle sources from 1972 to 1977. These imports amounted to a total of about $326 million in 1977.

9.1.8 Industry Growth

A number of forecasts of economic growth in the organic chemical industry are available. The annual growth rate used here, 5.9 percent, was estimated by McGraw Hill[10] for the basic organic chemicals industry. The McGraw Hill estimate was selected for the following reasons. First, the growth rate was calculated for a group of chemicals which closely corresponds

TABLE 9-6. INDUSTRIAL ORGANIC CHEMICALS: U.S. IMPORTS AND EXPORTS, 1966-77[9]

Year	Imports ($\$10^6$)	Exports[a] ($\$10^6$)
1966	48	211
1967	48	231
1968	67	292
1969	84	290
1970	91	336
1971	129	304
1972	150	320
1973	169	484
1974	259	930
1975	205	779
1976	294	1,008
1977	326	995

[a] Includes exports of some finished products. Figures include estimates and are not strictly comparable with imports or production.

TABLE 9-7. INDUSTRIAL ORGANIC CHEMICALS: U.S. TRADE, BY PRINCIPAL TRADING PARTNERS, 1976 AND 1977[9]

($\$10^3$)

Source	Imports[a]	Exports[b]	Trade balance
1976:			
West Germany	94,768	10,487	- 84,281
Japan	61,228	27,380	- 33,848
Italy	30,678	N.A.[c]	- 30,000
United Kingdom	24,709	15,497	- 9,212
Switzerland	17,280	2,681	- 14,599
France	12,371	11,401	- 970
Belgium	2,154	46,779	44,625
Canada	8,081	93,471	85,390
Netherlands	8,987	178,111	169,124
Mexico	3,452	63,964	60,512
Argentina	1,927	N.A.[c]	- 1,500
Brazil	98	59,444	59,346
All other	28,103	498,985	470,882
Total	293,836	1,008,200	714,364
1977:			
West Germany	105,172	5,038	-100,134
Japan	65,770	30,736	- 35,034
Italy	32,711	N.A.[c]	- 32,500
United Kingdom	31,132	27,458	- 3,674
Switzerland	21,956	6,541	- 15,415
France	15,763	N.A.[c]	- 15,500
Belgium	9,839	61,126	51,287
Canada	7,270	82,676	75,406
Netherlands	4,858	156,581	151,723
Mexico	4,673	62,965	58,292
Argentina	3,353	6,283	2,930
Brazil	538	78,512	77,974
All Other	22,865	477,469	454,604
Total	325,900	995,385	669,485

[a] Data represent customs import value, the value appraised by the U.S. Customs Service in accordance with the legal requirements of sec. 402 and 402a of the Tariff Act of 1930, as amended.

[b] Includes exports of some finished products. Figures include estimates and are not strictly comparable with imports.

[c] N.A. = Not available.

TABLE 9-8. INDUSTRIAL ORGANIC CHEMICALS: U.S. IMPORTS FOR CONSUMPTION, BY PRINCIPAL SOURCES, 1972-77[9]

($\$10^3$)[a]

Source	1972	1973	1974	1975	1976	1977
West Germany	66,085	72,715	84,059	62,145	94,768	105,172
Japan	36,181	29,793	65,027	49,243	61,228	65,770
Italy	11,305	10,705	17,323	19,073	30,678	32,711
United Kingdom	7,605	10,433	21,119	18,820	24,709	31,132
Switzerland	11,593	16,063	15,846	14,773	17,280	21,956
France	1,611	4,233	8,585	9,797	12,371	15,763
Belgium	1,220	7,919	10,494	1,871	2,154	9,839
Canada	4,301	5,515	4,826	4,352	8,081	7,270
Netherlands	5,067	4,724	10,291	6,738	8,987	4,858
Mexico	35	486	1,812	388	3,452	4,673
Argentina	3	--	--	657	1,927	3,353
All other	5,031	6,892	19,190	17,625	28,201	23,403
Total	150,037	169,478	258,572	205,482	293,836	325,900

[a] Customs import value, the value appraised by the U.S. Customs Service in accordance with the legal requirements of sec. 402 and 402a of the Tariff Act of 1934, as amended.

to the SOCMI chemicals. Second, the method used by McGraw Hill to develop the growth rate is internally consistent and takes account of forecasted developments in the U.S. economy. Third, the projections are developed for the period 1976-1991, entirely covering the forecast period of interest in this study (1981-1985).

In order to estimate the number of new model units covered by the regulatory alternatives, it is assumed that the number of operating facilities will grow at the same rate as the industry's output. It is further assumed that any regulatory alternative will take effect on January 1, 1981, and therefore that the fifth year of the impact analysis is 1985. In 1976 (the most recent year for which data are available), 1,334 facilities manufactured SOCMI chemicals in the U.S.[11] If the industry grows at an annual rate of 5.9 percent, by the beginning of 1981 this number will have risen to 1,678 facilities and by the end of 1985 to 2,235 facilities. Thus, an estimated 557 units built to provide additional capacity for the industry will be covered by the regulatory alternatives.

The regulatory alternatives will also cover units constructed to replace existing capacity which "wears out" during the period. The number of replacement units is estimated on the basis of the following assumptions. First, units have a working life of 20 years. Second, the historical growth rate for SOCMI prior to 1977 was 6 percent per year. Using these assumptions, it is estimated that 274 new units will be required to replace the part of the existing capacity that will "wear out" over the period 1981 to 1985. The methodology used to compute this estimate is described in detail in Appendix E2.

The estimates for entirely new units, combined with estimates for replacement facilities, indicate a total of 831 units that will be affected by the regulation. To estimate the number of A, B and C model units (identified in Section 6.1) that will be constructed between 1981 and 1985, it is assumed that the mix of model units will not change over time, and that the percentages of A, B and C model units are as follows:

Model unit	Percent of existing units
A	52
B	33
C	15

TABLE 9-9. INDUSTRY CONCENTRATION, 1976[4]

Number of firms	Percent of firms	Estimated capacity (gg)	Percent of industry capacity
Top 4	0.72	58.75	18.3
Top 8	1.43	91.82	28.6
Top 20	3.58	145.75	45.4
Top 40	7.17	186.68	58.1

If these percentages are applied to the estimate of the total number of units presented above, they imply that 432 A units, 274 B units and 125 C units will be affected by the regulatory alternatives.

9.2 ECONOMIC IMPACT ANALYSIS

9.2.1 Market Structure and Financial Profile

SOCMI producers manufacture chemicals, each of which has its own national and regional markets. Consequently, SOCMI firms encounter a wide range of market situations for the different chemicals they produce. Many SOCMI chemicals, for example, formaldehyde, urea and benzene, are manufactured by a relatively large number of firms using an array of different processes. The products have a wide range of end uses in which substitute materials can often be used. Thus industry-wide elasticities of demand for the chemicals are relatively high. In this type of market situation, producers have little or no ability to pass on cost increases to consumers in the form of higher market prices. Other SOCMI chemicals, for example, succinonitrile, isoamylene, and methyl butynol, are manufactured by a small number of producers and in some cases only one producer, and have no close substitutes in their end uses. In these oligopolistic and monopolistic markets, producers may be able to exercise considerable influence on market prices and to pass on a large part or all of any production cost increases in the form of higher prices.

The ability of firms to pass on cost increases in the form of price increases is influenced by the extent to which the industry is vertically and horizontally integrated. There is extensive vertical integration within the SOCMI. Captive consumption in the industry averaged 53.7 percent* of total output during the period 1967-1978, and this ratio varied only slightly from year to year. The precise degree of horizontal integration within SOCMI is difficult to evaluate because it varies considerably among products. However, a general assessment of the industry-wide situation may be made using the capacity share data presented in Table 9-9. These data suggest that no one company or group of companies has a dominant position within the industry. In 1976, the top four companies owned only 18.3 percent and the top twenty firms 45.4 percent of total SOCMI capacity. There is no reason to believe that the extent of industry-wide market concentration has altered significantly since that time.

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*This figure is estimated from data presented in Table 9-4.

Data on the returns on equity, returns on debt, returns on preferred stock, debt-asset ratios, equity-asset ratios and preferred stock-asset ratios were collected for a sample of 100 chemical manufacturing firms for the most recent available years.† These data are presented in Table E3-2. The data have been used to estimate the cost of capital to firms in the SOCMI, using the assumption that the sample of firms in Table E3-2 is unbiased and normally distributed. A detailed discussion of the methodology used to estimate the cost of capital is presented in Appendix E3.

The estimated cost of capital, presented in Table 9-10, is used in Section 9.2.3 to estimate the economic impacts of SOCMI fugitive emissions regulatory alternatives. Note that the average aftertax cost of capital for chemical firms is 10.8 percent. On a pretax basis, this figure increases to 20.8 percent. If, as was assumed, capital costs are normally distributed, then 95 percent of the firms in the industry face aftertax costs of capital in the range of 9.0 percent to 12.7 percent and pretax costs of capital in the range of 17.2 percent to 24.4 percent.

9.2.2 Regulatory Alternatives

The four regulatory alternatives being considered are described in detail in Section 6.2. The baseline regulatory alternative (alternative I) does not require producers to implement additional control techniques. Consequently, model units complying with this alternative would not incur any incremental costs* and no economic impacts would result from its implementation. Regulatory alternatives II, III and IV require successively more stringent equipment inspections and equipment specifications. Firms

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†Data on the ratio variables and rates of return were available for 1977 and 1978, respectively.

*Incremental costs of a regulatory alternative are those additional costs a firm incurs in meeting the regulatory alternative that it would not incur in meeting the baseline alternative.

TABLE 9-10. ESTIMATED COST OF CAPITAL FOR FIRMS IN SOCMI[a]

	Aftertax cost of capital	Pretax cost of capital
Mean	10.807%	20.783%
Standard deviation	0.930	1.789
Minimum	8.015%	15.414%
Maximum	12.798%	24.612%

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[a] See Appendix E3 for details of the data and methodology used to estimate the cost of capital for firms in SOCMI.

complying with regulatory alternatives II, III and IV would therefore incur incremental costs, and consequently economic impacts would result from their implementation.

9.2.3 Economic Methodology

9.2.3.1 Regulatory Scenarios. Economic impacts are estimated for regulatory alternatives II, III and IV but not for regulatory alternative I, since firms will not incur incremental costs in complying with that alternative. The economic impacts associated with alternatives II, III and IV are estimated under two alternative assumptions about firm pricing behavior: (1) full cost absorption and (2) full cost pricing. Combining the three regulatory alternatives with the two alternative pricing models yields six regulatory scenarios:

	Regulatory Alternative	Pricing Policy
Scenario 1	Alternative II	Full Cost Absorption
Scenario 2	Alternative II	Full Cost Pricing
Scenario 3	Alternative III	Full Cost Absorption
Scenario 4	Alternative III	Full Cost Pricing
Scenario 5	Alternative IV	Full Cost Absorption
Scenario 6	Alternative IV	Full Cost Pricing

Under full cost absorption, the affected firm bears the full incremental costs of environmental controls, accepting a lower rate of return on its capital investment. Under full cost pricing, the firm adjusts product prices so as to maintain its current aftertax rate of return on capital investment.

The alternative assumptions about firm pricing behavior are associated with different market conditions in the affected industry. In both cases, firms are assumed to have no monopsony power in resource markets. Thus, they cannot pass back cost increases to resource suppliers. In the cost absorption case, the domestic industry as a whole is assumed to be a price taker, unable to affect the market price of its product either because of the existence of close product substitutes, or because of strong international competition in domestic and foreign markets. However, full cost pricing will take place if the industry produces a commodity for which no domestic or imported substitutes exist, or if the industry has constant costs. A constant-cost industry is one in which unit costs remain constant as industry output increases. Firms in such industries experience constant returns to scale.

In fact, firms in SOCMI face a wide variety of product market situations (see Section 9.2.1). Some firms will be able to fully pass through cost increases to consumers in the form of higher prices. Some will be able to pass on only a part of the cost increases. Others will be forced to fully absorb all regulatory control costs, leaving product prices unchanged. Consequently, the full cost pass through and full cost absorption scenarios evaluated below provide estimates of the maximum range of possible price and rate of return impacts for the different products and firms in SOCMI.

9.2.3.2 Estimation of Regulatory Price Impacts Under Full Cost Pricing. Under full cost pricing, the firm is assumed to respond to cost increases by adjusting product price to maintain a target rate of return on investment. The required price change (dP) may be calculated using the following equation:*

$$dP = \frac{dTOP + r\ dK/(1-t)}{Q} \qquad (1)$$

where dP = required change in product price

dTOC = total annual operating costs of compliance dk = total initial costs of compliance

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*The derivations of Equations (1) and (2) are presented in Appendix E4.

Q = total annual unit output

r = target rate of return

t = tax rate

9.2.3.3 Estimation of Rate of Return Impacts Under Full Cost Absorption. Under full cost absorption, an increase in facility production costs results in a lower rate of return on investment for the firm, because market conditions prohibit it from passing on cost increases to the consumer. The impact on the facility's rate of return on investment is given by the following equation:

$$-dr = \frac{r \cdot dK + (1-t)\ dTOC}{K} \qquad (2)$$

where dr = change in rate of return, and

K = preregulation level of capital investment.

Note that pretax rate of return impacts may be calculated by setting the tax rate variable, t, equal to zero in Equations (1) and (2). Also note that price and rate of return impacts are estimated on the assumption that capacity utilization rates remain constant (that is, Q remains unchanged). To the extent that the regulatory alternatives result in decreases (increases) in capacity utilization rates, price and rate of return impacts will be larger (smaller) than those estimated using Equations (1) and (2) because of economies of scale in the use of control techniques.

9.2.3.4 Other Economic Impacts. The price and rate of return impacts estimated by the above techniques are used to make a quantitative assessment of the probable impacts of the regulatory alternatives II, III, and IV on industry growth, new facility openings, the replacement of existing facilities, and investment levels. These data are then used to assess the extent of interindustry and macroeconomic impacts associated with the various regulatory alternatives.

9.2.3.5 Estimation Data. Estimation of price and rate of return impacts for different model units requires data on the following variables: (1) total acquisition and installation costs of the control equipment (dK), (2) total annual operating costs of the control equipment and monitoring procedures (dTOC), (3) the preregulation capital stock (k), (4) the target rate of return (r), (5) the tax rate (t), and (6) model unit production levels (Q). Data on dK and dTOC for each of the three model units identified as representative of the industry* were obtained from Section 8.1 The tax rate is assumed to be 48 percent. Data on model unit production levels were obtained from the 1976 Organic Chemical Producers Data Base for each of the units covered by the regulatory alternatives. The 831 model units are assumed to be distributed by capacity in an identical manner to the 1,105 units for which both value of product and quantity data are available in the 1976 Organic Chemical Producers Data Base. Thus, the number of new units with a given capacity, say 100 Gg, is assumed to be equal to the number of units in the data base (831/1,105). Actual unit output levels are obtained by applying a capacity utilization rate to the estimated unit capacities.

To evaluate industry-wide impacts, the cost data from Section 8.1 were adjusted to allow for higher or lower product recovery credits for chemicals with a value greater or less than $0.36/kg. For such chemicals, product recovery credits were estimated by multiplying estimated product savings by the price of the chemical in question.

Data on the value of the preregulation capital stock for plants of different capacities were calculated as follows: A capital-capacity coefficient for firms in SOCMI was obtained by dividing the estimated total value of industry assets in 1976 by the volume of output produced in that year.** The estimate of the capital-output coefficient was converted into a capital-capacity coefficient by multiplying the capital-output coefficient by an assumed industry-wide capacity utilization rate. The assumed capacity utilization rate for 1976 was 50 percent. This capacity utilization estimate was based on the assumption that the typical capacity utilization for the industry is 75 percent. In 1976, output was 9.2 percent below the industry-wide high level of output achieved in 1974. Between 1974 and 1976 it is probable that some additions to industry capacity were made. Hence, the assumption of a 50 percent capacity utilization rate for 1976, though somewhat arbitrary, is not unreasonable. The 1976 capital-capacity coefficient was updated to last quarter 1978 dollars using the machinery and equipment price index computed by the United States Department of Commerce.[12] The capital-capacity coefficient estimated by the above procedure was $125/Mg of product. This coefficient was multiplied by model unit capacity to obtain an estimate of K for each model unit considered in the analysis.

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*See Chapter 6 for a detailed discussion of the model units.

**See Tables 9-4 and 9-5 for data on production and total industry assets.

Estimates of pretax and post-tax rates of return used in the analysis are presented in Table 9-10. These data were obtained from an analysis of a sample of 100 firms in the SOCMI industry. Details of the analysis are contained in Appendix E3.

9.2.4 Economic Impacts

9.2.4.1 Rate of Return Impacts Data on unit capacity, product value, capital investment and tax rates are available for 1,105 units in the 1976 Organic Chemical Producers Data Base.[4] Price data were updated using the Chemical Marketing Reporter.[13] Capital stock estimates were also expressed in 1978 prices. These data were used in conjunction with the cost information presented in Section 8.1 to calculate full cost absorption rate of return impacts of regulatory alternatives II, III, and IV for the 831 model units projected to be built. It is assumed in estimating the rate of return impacts presented here that the 831 new model units will have the same capacity and product value distributions as the units in the Organic Chemical Producers Data Base, and that capacity utilization for each unit is 50 percent. This relatively low capacity utilization rate is used to estimate unit output levels because it represents a feasible worst-case economic scenario for the industry (that is, economic conditions similar to those experienced in 1976). As a result, actual impacts are likely to be less adverse than those presented below.

Rate of return impacts are estimated on the basis of these assumptions for each of the 831 new model units covered by the regulatory alternatives. It is probable that the assumption of a constant product price distribution also results in an overestimate of adverse rate of return and price impacts, since the prices of the products manufactured by SOCMI are expected to increase between 1979 and 1985 as energy and feedstock costs rise. Any real increase in product prices will raise the value of product recovery credits, lower the net costs of compliance associated with any given regulatory alternative, and thereby reduce adverse rate of return and price impacts.

Rate of return impacts for A, B, and C average model units under each regulatory alternative are presented in Table 9-11. Each of these average model units is assumed to manufacture products valued at approximately $0.36/kg, to have an annual capacity of 84,678 Mg and to have an existing cost of capital of 10.81 percent. These average model units differ only in terms of the complexity of the processes they use to manufacture the chemicals. The product value and rate of return data represent the means for each variable in the samples used in the analysis. Under regulatory alternatives II and III, each average model unit experiences a very small increase, not a decrease, in its aftertax rate of return on investment, regardless of the process it uses. This result is obtained because at a price of $0.36/kg for recovered product, product recovery credits exceed total annualized costs of control. Under regulatory alternative IV, average model unit of types A and B experience small decreases in aftertax rates of return on investment. Model C units experience rate of return decreases amounting to 1.12 percentage points, still quite small adverse impacts.

The data presented in Table 9-11 suggest that some firms may benefit from the implementation of any regulatory alternative. These results are subject to the following qualifications. In the above analysis, it is assumed that firms will not independently implement the emissions controls proposed in the regulatory alternatives. In fact, if there are significant net cost reductions to be achieved from additional emissions controls, firms will voluntarily adopt them. Under such circumstances, the cost reductions associated with any regulatory alternative will be considerably smaller. Note that incentives for voluntary emissions controls increase as the value of the manufactured product increases. As some SOCMI producers manufacture highly valued products with prices in excess of $0.50/kg, they are likely to be willing to use extensive emissions control techniques in the absence of any NSPS.

TABLE 9-11. AVERAGE RATE OF RETURN IMPACTS[a]

Model Units	Change in rate of return (percentage points)		
	Alternative II	Alternative III	Alternative IV
Unit A	+0.000	+0.000	-0.16
Unit B	+0.003	+0.001	-0.37
Unit C	+0.006	+0.005	-1.12

[a] Impacts are estimated on the assumption that the initial aftertax rate of return on investment is 10.807 percent, the mean cost of capital presented in Table 9-10; the initial price of the product is $0.36/kg; plant capacity is 84,678 Mg; and the capacity utilization rate is 50 percent.

Although in general firms will not be affected by the implementation of regulatory alternatives II, III, and IV, because of wide variation in productive capacity and value of product among model units, some will experience adverse rate of return impacts. Estimates of the numbers of model units experiencing rate of return decreases in excess of one and two percentage points as a result of the implementation of each regulatory alternative are presented in Table 9-12. These estimates were obtained by calculating rate of return impacts for each of the 831 new model units under the assumption that 52 percent, 33 percent, and 15 percent of all units of all sizes are A, B and C model units, respectively. Under regulatory alternatives II and III, the estimated number of adversely affected units is very small; only 6 and 12 units, out of a total of 831 model units, experience rate of return decreases of more than one percentage point. Under regulatory alternative IV, a much larger number of units, 93 in all, are estimated to experience rate of return decreases in excess of 1 percent under a full cost absorption scenario. It should be noted that most of these adversely affected units are B and C model units rather than A model units. In fact, all B and C model units with capacities in excess of 26,464 and 89,121 Mg, respectively, producing chemicals with prices exceeding $0.15/kg, will experience rate of return impacts smaller than one percentage point even under alternative IV. The EPA estimates that virtually all B and C model units do in fact have capacities in excess of this figure,[14] and furthermore, industry sources indicate that most produce chemicals that have prices in excess of $0.15/kg.[13] If the estimated impacts on B and C model units are ignored, only 25 units are likely to be adversely affected by regulatory alternative IV.

9.2.4.2 Price Impacts. The potential price impacts of regulatory alternatives II, III, and IV are also estimated under the assumption that capacity and value of product distributions will remain constant over the forecast period, 1979-1985. The price impact estimates are therefore subject to the same limitations as the rate of return impact estimates discussed above. Potential price impacts for A, B and C model units with average capacities of 84,678 Mg and product values of $0.36/kg are presented in Table 9-13. Under regulatory alternatives II and III, price impacts are

TABLE 9-12. MODEL UNITS EXPERIENCING SIGNIFICANT RATE OF RETURN IMPACTS UNDER FULL COST ABSORPTION[a]

Model units	Alternative II		Alternative III		Alternative IV	
	dr < -1%	dr < -2%	dr < -1%	dr < -2%	dr < -1%	dr < -2%
Unit A	6	4	7	5	25	12
Unit B	0	0	4	2	34	16
Unit C	0	0	1	0	34	20
Total	6	4	12	7	93	48

[a] dr denotes the percentage point change in firms' rates of return on investment.

TABLE 9-13. AVERAGE PERCENTAGE PRICE IMPACTS OF REGULATORY ALTERNATIVES[a]

Model units	Price changes (percent)		
	Alternative II	Alternative III	Alternative IV
Unit A	-0.000	-0.000	+0.000
Unit B	-0.002	-0.002	+0.000
Unit C	-0.009	-0.007	+0.733

[a] Impacts are estimated on the assumption that the target rate of return is 10.807 percent, the average cost of capital presented in Table 9-10; the initial price of the product is \$0.36/kg; plant capacity is 84,678 Mg; and the capacity utilization rate is 50 percent.

negative for each type of model unit because annual product recovery credits exceed the total annualized cost of the monitoring procedures and capital equipment required under these alternatives. Under regulatory alternative IV, extremely small positive price impacts occur. In general most units will not increase product prices as a result of the implementation of regulatory alternatives II, III or IV. However, because of the variations in capacity and product value within the industry, some firms may have to raise product prices in order to maintain existing rates of return on investment. In some cases, the price increases required by individual facilities are in excess of 5 percent and even 6 percent of the current product price. Data on the estimated numbers of such units are presented in Table 9-14. These estimates are also obtained by calculating price impacts for each of the 831 new model units under the assumption that units are distributed among A, B, and C model units in the manner described above and operate at 50 percent of unit capacity. Under alternatives II and III, only five A and eight B model units would have to increase product prices by more than 5 percent. Under alternative IV, 30 units must increase prices by more than 5 percent preregulation rates of return on investment. However, it should be noted that these estimates may overstate the extent of significant price impacts under regulatory alternative IV. Most of the units estimated to require price increases in excess of 5 percent are C model units. In fact, C model units that manufacture chemicals with prices in excess of \$0.15/kg and have capacities greater than 71,550 Mg do not have to increase product prices by more than 5 percent to maintain their target rates of return on investment. The EPA estimates that virtually all plants using processes with the same degree of complexity as that assumed for C model units have larger capacities and produce products with higher values than these.[13] In addition, model units are assumed to operate at the relatively low capacity utilization rate of 50 percent.

A final caveat concerning price and rate of return impacts should be noted. The impact estimates presented in Tables 9-12 and 9-14 were developed on the assumption that feedstock prices are unaffected by the implementation of any regulatory alternative. However, as the industry extensively uses its own products as feedstocks, this assumption is not strictly valid and

TABLE 9-14. MODEL UNITS REQUIRING SIGNIFICANT PRICE INCREASES TO MAINTAIN TARGET RATES OF RETURN

Model Units	Alternative II Price increase ≥ 5%	Alternative II Price increase ≥ 6%	Alternative III Price increase ≥ 5%	Alternative III Price increase ≥ 6%	Alternative IV Price increase ≥ 5%	Alternative IV Price increase ≥ 6%
Unit A	4	4	4	4	6	5
Unit B	0	0	2	2	10	9
Unit C	0	0	0	0	14	12
Total	4	4	6	6	30	26

introduces a systematic upward bias in the estimated size of adverse rate of return and potential price impacts. The upward bias occurs because, in general, firms adopting alternative II, III and IV control technologies will achieve net cost reductions and, at least in competitive markets, will tend to reduce rather than increase the prices of products used as feedstocks by the industry.

9.2.4.3 Investment Impacts. It is difficult to assess the impact of any of the standards on the number of units to be constructed between January 1, 1981, and December 31, 1985, because of the variations in these impacts across units. Some smaller facilities may not be erected as a result of the standard because of adverse impacts on rates of return and price competitiveness. Other larger facilities may be built because production costs fall as a result of emissions reductions and product recovery credits. Therefore, in this analysis it is assumed that implementation of regulatory alternatives II, III, and IV will have no measurable impact on the number of new facilities constructed between 1981 and 1985, the 5-year period following proposal of any regulatory alternative. Industry-wide investment impacts are therefore simply the incremental capital costs associated with the acquisition of the capital and monitoring equipment required under each regulatory alternative by the 831 new units expected to be constructed between 1981 and 1985.

Data on these investment impacts are presented in Table 9-15. The estimates are obtained by assuming that 432 A model plants, 274 B model units, and 125 C model units will be constructed and that, as a result of each regulatory alternative, these units incur incremental capital costs equal to those presented in Section 8.2. Under regulatory alternatives II and III, industry-wide investment impacts are quite small, less than $22 million. Under regulatory alternative IV, they increase substantially to almost $233 million. Nevertheless, even under regulatory alternative IV, the total 5-year investment impacts of any of the regulatory alternatives would be less than 1.14 percent of total industry assets in 1976 and less than 1.64 percent of the value of industry sales in 1978.* It appears, therefore, that the

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*Data on total industry value of assets and industry sales are presented in Tables 9-4 and 9-5.

TABLE 9-15. INVESTMENT IMPACTS

Model units	Number of model units	Incremental model unit costs of control ($$10^6$)	Incremental industry costs of control ($$10^6$)
Regulatory alternative II			
Unit A	432	0.0132	5.7
Unit B	274	0.0272	7.5
Unit C	125	0.0660	8.3
Total	831	---	21.5
Regulatory alternative III			
Unit A	432	0.0132	5.7
Unit B	274	0.0272	7.5
Unit C	125	0.0660	8.3
Total	831	---	21.5
Regulatory alternative IV			
Unit A	432	0.0871	37.6
Unit B	274	0.2950	80.8
Unit C	125	0.9110	113.9
Total	831	---	232.3

industry as a whole will not have much difficulty in obtaining the investment funds to acquire required control equipment under any of the regulatory alternatives.

9.2.4.4 Employment Impacts. Regulatory alternatives II, III, and IV will each have small but measurable impacts on employment in SOCMI because they require firms to intensify monitoring and maintenance schedules to control fugitive emissions. Estimates of the number of additional workers required as a result of each regulatory alternative are presented in Table 9-16. The estimates were obtained by multiplying the projected numbers of each type of affected facility by the unit-by-unit, person-year monitoring and maintenance requirements for each standard presented in section 8.1* The largest employment impacts (400 workers) are associated with regulatory alternative III, which requires more stringent monitoring programs than alternative II. Under alternative IV, some alternative III monitoring requirements are replaced by equipment controls, reducing incremental employment requirements to approximately 225 workers. The employment impacts of each of the standards are small relative to total employment in the industry, representing no more than 0.6 percent of the 1976 SOCMI work force in each case.

9.2.4.5 Total Annualized Costs of Control. Total incremental annualized costs of control for the fifth year following promulgation of alternatives II, III, or IV are presented in Table 9-17. Product recovery credits are calculated using the fourth quarter 1978 industry-wide average product price of $0.36/kg. Under regulatory alternatives II and III, the industry as a whole is estimated to reduce annualized production costs by $28.73 million and $21.35 million, respectively. Under regulatory alternative IV, annualized production costs are estimated to increase by $11.17 million. If the above estimates are accurate in the minimal sense that they indicate the direction in which production costs will move and their approximate order of magnitude, then it may be concluded that none of the regulatory alternatives will result in any measurable industry-wide increase in prices.

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*A person-year is assumed to consist of 2,000 person-hours.

TABLE 9-16. EMPLOYMENT IMPACTS
(Person-years)

Model unit	Alternative II		Alternative III		Alternative IV	
	Unit	Industry	Unit	Industry	Unit	Industry
Unit A	0.1237	53.43	0.1855	80.14	0.0579	25.01
Unit B	0.1863	51.05	0.5079	139.16	0.2277	62.39
Unit C	0.5017	62.71	1.4532	181.65	1.0982	137.27
All units		167.19		400.95		224.67

TABLE 9-17. MODEL UNIT AND INDUSTRY ANNUALIZED CONTROL COSTS

Regulatory alternative	No. of model units	Incremental unit annualized costs without product recovery credit ($$10^3$)	Incremental unit annualized costs with product recovery credit[a] ($$10^3$)	Incremental industry annualized costs with product recovery credit[a] ($$10^3$)
Alternative II				
Unit A	432	12.1	- 3.3	- 1,430
Unit B	274	20.3	- 38.5	-10,550
Unit C	125	48.3	-134.0	-16,750
Total				-28,730
Alternative III				
Unit A	432	15.0	- 1.7	- 730
Unit B	274	35.5	- 28.3	- 7,750
Unit C	125	95.1	-103.0	-12,870
Total				-21,350
Alternative IV				
Unit A	432	29.0	7.9	3,410
Unit B	274	93.5	13.3	3,640
Unit C	125	283.0	33.0	4,120
Total				11,170

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[a] Product recovery credits estimated on the basis of an assumed product value of $0.36/kg.

9.2.4.6 Interindustry Impacts. Interindustry impacts will be negligible, because net annualized costs of control are extremely small relative to the value of total industry output, representing less than 0.03 percent of the value of 1978 output in even the most adverse case (regulatory alternative IV).

9.3 SOCIO-ECONOMIC AND INFLATIONARY IMPACTS

The socio-economic and inflationary impacts of alternatives II, III and IV will be very small.

(1) Annualized Costs: In the fifth year following promulgation, the regulatory alternatives, if implemented, are estimated to result in either annualized cost reductions or very small annualized cost increases. Consequently, none of the alternatives violates the regulatory criterion of $100 million.

(2) Price Impacts: Because industry-wide annualized costs of compliance for alternatives II, III and IV are estimated to be negative or extremely small relative to the value of industry output, none of the standards is likely to cause any industry-wide price increases.

9.4 REFERENCES

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14. Memo from Hustvedt, K.C. November 7, 1980. Model Unit Capacities.

APPENDIX A
EVOLUTION OF THE PROPOSED STANDARDS

Date	Action
December 1978	Work began on developing standards for new sources in SOCMI.
3-5 January 1979	Testing at Stauffer Chemical Company in Louisville, Kentucky (SOCMI Unit C).
2 February 1979	Letter to Stauffer Chemical Company requesting information pertaining to testing at SOCMI Unit C.
16 February 1979	Section 114 letter to Phillips Petroleum Company requesting permission to perform emission sampling of plant equipment.
27 February 1979	Letter to Phillips Petroleum Company requesting information on plant's directed maintenance program.
5-8 March 1979	Testing at Phillips Petroleum in Sweeny, Texas (SOCMI Unit D).
9 March 1979	Letter to Exxon Chemical Company requesting information on fugitive emissions from cyclohexane unit.
14 March 1979	Comments requested from industry on Hydroscience Draft Fugitive Emissions Report.
21 March 1979	Letter from Exxon Chemical Company U.S.A. Response to request for information on fugitive emissions from cyclohexane unit.

Date	Action
10 April 1979	Letter from Exxon Chemical Company USA. Comments on Hydroscience draft, "Fugitive Emissions Report," Feb. 1979.
10 April 1979	Letter from Tennessee Eastman Company. Comments on Hydroscience draft "Fugitive Emission Report," Feb. 1979.
	Letter from Phillips Petroleum Company. Comments on Hydroscience draft "Fugitive Emission Report," Feb. 1979.
12 April 1979	Letter from Shell Oil Company. Comments on Hydroscience draft Fugitive Emissions Report, Feb. 1979.
12 April 1979	Letter from Vulcan Materials Company. Review of the Hydroscience draft Fugitive Emission Report.
3 May 1979	Letter from American Cyanamid Company. Comments on Hydroscience Draft "Fugitive Emissions Report," Feb. 1979.
8 May 1979	Letter from B.F. Goodrich Company. Comments on Hydroscience draft "Fugitive Emissions Report," Feb. 1979.
17 May 1979	Letter from Texas Chemical Council. Comments on Hydroscience draft "Fugitive Emissions Report," Feb. 1979
1 June 1979	Letter from Atlantic Richfield Company. Comments on Hydroscience draft "Fugitive Emissions Report." Feb. 1979.

Date	Action
12 June 1979	Discussion of fugitive emissions sampling at DuPont Chemical plants.
20 June 1979	Meeting with California Air Resources Board in Sacramento, California. Discussions of fugitive emissions and regulations.
21 June 1979	Meeting with ARCO in Carson, California. Discussion of fugitive emissions and regulations.
21 June 1979	Meeting with Chevron in El Segundo, California. Discussion of fugitive emissions and regulations.
21 June 1979	Meeting with South Coast Air Quality Maintenance District in El Monte, California. Discussion of fugitive emissions and regulation.
19 July 1979	Chemical Manufacturers Association/Texas Chemical Council Fugitive Emission Seminar, Washington, D.C.
17 October 1979	Letter from Century Systems Corporation. Cost data for portable VOC detection instrument.
24 October 1979	Letter to Exxon Chemical Company requesting information on leak-free technology.
24 October 1979	Letter to Dow Chemical U.S.A. requesting information on leak free technology.
7 November 1979	Chapters 3-6 of Background Information Document sent out for public review.
12 November 1979	Letter from Chemical Manufacturers Association. Comments on Hydroscience draft "Fugitive Emissions Report," Feb. 1979.

Date	Action
3 January 1980	Letter from Shell Oil Company. Comments on draft BID sections, "Fugitive Emission Sources in the Synthetic Organic Chemicals Manufacturing Industry," Nov. 1979.
4 January 1980	Letter from Phillips Petroleum Company. Comments on draft BID sections, "Fugitive Emission Sources in the Synthetic Organic Chemicals Manufacturing Industry," Nov. 1979.
10 January 1980	Letter from Vulcan Materials Company. Comments on draft BID sections, "Fugitive Emissions Sources in the Synthetic Organic Chemicals Manufacturing Industry." Nov. 1979.
5 February 1980	Letter from 3M. Comments on draft BID sections, "Fugitive Emission Sources in Synthetic Organic Chemicals Manufacturing Industry," Nov. 1979.
12 February 1980	Letter from Chemical Manufacturers Association. Comments on Leak-Free Technology for Control of Benzene Fugitive Emissions.
2 April 1980	Meeting with CMA in Durham, North Carolina to discuss recommended standard.

Date	Action
16 April 1980	Recommended Standard presented at NAPCTAC meeting in Raleigh, North Carolina.
21 April 1980	Letter from Colt Industries. Comments on Selection of Packing.
23 April 1980	Letter from South Coast Air Quality Management District. Comments about recommended rules.
28 April 1980	Letter from American Cyanamid Company. Comments on draft regulations discussed at April 16-17 NAPCTAC meeting.
28 April 1980	Letter from 3M Corporation. Comments on draft regulations discussed at April 16-17 NAPCTAC meeting.
29 April 1980	Letter from Oxirane Corporation. Comments concerning draft SOCMI regulations.
1 May 1980	Telephone discussion with Hartford Steam Boiler Insurance and Inspection Company engineering department about use of rupture disks and relief valves.
1 May 1980	Telephone discussion with Brown & Root, Inc., about use of rupture disks and relief valves.
2 May 1980	Letter from Brown and Root. Information concerning relief devices.
20 May 1980	Meeting with Furmanite to discuss valve repairability.

Date	Action
27 May 1980	Letter from Chemical Manufacturers Association. Comments on SOCMI regulations.
28 May 1980	Letter to A.W. Chesterton. Request for information on pump seal performance.
3 June 1980	Letter from L. Bentsen, U.S. Senate. Texas Chemical Council Comments on development of SOCMI standard.
4 June 1980	Letter from J. Brooks, U.S. House of Representatives. Texas Chemical Council Comments on development of SOCMI standard.
5 June 1980	Letter from B. Eckhardt, U.S. House of Representatives. Comments on development of SOCMI standard by The Upjohn Company.
5 June 1980	Letter from J. Tower, U.S. Senate. Comments on development of SOCMI standard by the Upjohn Company.
12 June 1980	Letter from Chemical Manufacturers Association. Draft comments on development of SOCMI fugitive standard.
13 June 1980	Letter from Chemical Manufacturers Association. Comments on draft Hydroscience report.
16 June 1980	Meeting with DuPont in Durham, North Carolina. Discussion of skip period monitoring.
17 June 1980	Meeting with Chemical Manufacturers Association/ Texas Chemical Council. Discussion of draft SOCMI regulations.

Date	Action
30 June 1980	Letter from Texas Chemical Council. Comments on Draft BID and recommended SOCMI standard.
18 July 1980	Meeting with Texas Chemical Council in Durham, North Carolina. Discussion of Draft BID and recommended standard.
28 July 1980	Letter from Texas Chemical Council. Information concerning "capital creep."
18 August 1980	Letter from UOP. Questions about draft regulations.

APPENDIX B

INDEX TO ENVIRONMENTAL CONSIDERATIONS

This appendix consists of a reference system which is cross indexed with the October 21, 1974, Federal Register (39 FR 37419) containing EPA guidelines for the preparation of Environmental Impact Statements. This index can be used to identify sections of the document which contain data and information germane to any portion of the Federal Register guidelines.

TABLE B-1. INDEX TO ENVIRONMENTAL CONSIDERATIONS

Agency Guideline for Preparing Regulatory Action Environmental Impact Statements (39 FR 37419)	Location Within the Background Information Document
(1) Background and summary of regulatory alternatives	
Regulatory alternatives	The regulatory alternatives are summarized in Chapter 1, Section 1.1, pages 1-1 through 1-4.
Statutory basis for proposing standards	The statutory basis for the proposed standards is summarized in Chapter 2, Section 2.1, pages 2-1 through 2-5.
Affected industry	A discussion of the industry affected by the regulatory alternatives is presented in Chapter 3, Section 3.1, pages 3-1 through 3-3. The industry is further defined in Appendix F. Details of the "business/economic" nature of the industry are presented in Chapter 9, pages 9-1 through 9-35.
Affected sources	A description of the sources affected by the regulatory alternatives is presented in Chapter 3, Section 3.2, pages 3-3 through 3-17.
Availability of control technology	A discussion of available emission control techniques is presented in Chapter 4, Sections 4.1 and 4.2, pages 4-1 through 4-24.

TABLE B-1. (CONTINUED)

Agency Guideline for Preparing Regulatory Action Environmental Impact Statements (39 FR 37419)	Locations Within the Background Information Document
(2) Environmental, Energy, and Economic Impacts of Regulatory Alternatives	
Regulatory alternatives	Various regulatory alternatives are discussed in Chapter 6, Section 6.2, pages 6-4 through 6-7.
Environmental impacts	The environmental impacts of the various regulatory alternatives are presented in Chapter 7, Sections 7.1, 7.2, and 7.3, pages 7-1 through 7-12.
Energy impacts	The energy impacts of the various regulatory alternatives are discussed in Chapter 7, Section 7.4, pages 7-12 through 7-13.
Cost impacts	Cost impacts of the various regulatory alternatives are discussed in Chapter 8, pages 8-1 through 8-27.
Economic impacts	The economic impacts of the various regulatory alternatives are presented in Chapter 9, pages 9-1 through 9-35.

TABLE B-1. (CONTINUED)

Agency Guideline for Preparing Regulatory Action Environmental Impact Statements (39 FR 37419)	Location Within the Background Information Document
(3) Environmental impact of the regulatory alternatives	
Air pollution	The impact of the proposed standards on air pollution is presented in Chapter 7, Section 7.1, pages 7-1 through 7-8.
Water pollution	The impact of the proposed standards on water pollution is presented in Chapter 7, Section 7.2, pages 7-8 through 7-11.
Solid waste disposal	The impact of the proposed standards on solid waste disposal is presented in Chapter 7, Section 7.3, pages 7-11 through 7-12.

APPENDIX C
EMISSION SOURCE TEST DATA

The purpose of Appendix C is to describe testing results used in the development of the Background Information Document (BID) for fugitive emissions from the Synthetic Organic Chemicals Manufacturing Industry (SOCMI). The information in this appendix consists of a description of the tested facilities, and the sampling procedures and test results of fugitive emissions studies in SOCMI and the petroleum refining industry.

Fugitive emission sources in SOCMI and in the petroleum refining industry are similar. Considerable data exist concerning both the incidence and magnitude of fugitive emissions from petroleum refineries. Studies of fugitive emissions in SOCMI have been undertaken by EPA to support the use of emission factors generated during studies of emissions in petroleum refineries for similar sources in the Synthetic Organic Chemicals Manufacturing Industry. The results of the EPA SOCMI studies, EPA data from a study of fugitive emissions from petroleum refineries, and some industry studies of fugitive emissions are discussed in Section C.1.

Section C.2 consists of the results of three studies on the effects of maintenance on reducing fugitive VOC emissions from valves in petroleum refineries and one study on maintenance of valves in a SOCMI process unit. These results are included as an indication of the reduction in emissions which could be expected as a function of the designated action level, and by applying routine on-line maintenance procedures.

C.1 FUGITIVE EMISSIONS TEST PROGRAMS

Three SOCMI test programs have been conducted by EPA. One was a study performed by Monsanto Research Corporation of a small number of fugitive emission sources in four SOCMI units. More intensive screening was performed at six SOCMI units in another study. The third EPA study of SOCMI fugitive emissions was a screening and sampling program conducted at twenty-four SOCMI units. The results of these studies are presented in this section. Similar types of studies have been performed by industry. This section also contains the results of an Exxon study of fugitive emissions in cyclohexane unit and a DuPont study of fugitive emissions in unidentified process units.

The results of a study on fugitive emissions from petroleum refineries are also presented in this section. Data on fugitive emissions were obtained from 64 units in thirteen refineries located in major refining areas throughout the country. Data on the effects of maintenance were obtained at the last four of these refineries. These results are presented later in Section C.2 of this Appendix.

C.1.1 Study of Fugitive Emissions At Four SOCMI Units[1]

Monsanto Research Corporation conducted an EPA-IERL sponsored study of fugitive emissions at four SOCMI units. The process units were monochlorobenzene, butadiene, ethylene oxide/glycol, and dimethyl terephthalate. Due to the small number of plants/processes sampled and the experimental design of this study, the results were not considered to be comparable with the results of other studies. Since the data generated by the MRC study could not be considered representative of the SOCMI and valid conclusions could not be drawn concerning the relative magnitude of fugitive emissions in the SOCMI, the results of the study were not used in the development of standards for fugitive emissions control. This study demonstrated the need for more intensive sampling and screening which was undertaken by EPA.

C.1.2 Description and Results of EPA Study of Six SOCMI Units[2,3,4,5]

The objective of this test program was to gather data on the percentage of sources which leak (as defined by a VOC concentration at the leak interface of $\geq$10,000 ppmv calibrated with methane). To achieve this objective, an attempt was made to screen all potential leak sources (generally excluding flanges) on an individual component basis with a portable organic vapor analyzer. The test crews relied on plant personnel to identify equipment handling organics. Normally, all pumps and compressor seals were examined, and the percentage of valves carrying VOC which were screened ranged from 33 to 85 percent. All tests were performed with a Century Systems Corporation Organic Vapor Analyzer, Model 108, with the probe placed as close to the source as possible. The results of this study are shown in Table C-1.

Six chemical process units were screened. Unit A is a chlorinated methanes production facility in the Gulf Coast area which uses methanol as feedstock material. The individual component testing was conducted during September 1978. Unit B is a relatively small ethylene production facility on the West Coast which uses an ethane/propane feedstock. Testing was conducted during October 1978. Unit C is a chlorinated methanes production facility in the Midwest. This plant also uses methanol as the basic organic feedstock. Over the last few years, several pieces of equipment have been replaced with equipment the company feels is more reliable. In particular, the company has installed certain types of valves which they have found do not leak "as much" as other valves. The individual component testing was conducted during January 1979. Unit D is an ethylene production facility on the Gulf Coast, using an ethane/propane feed. The facility is associated with a major refinery, and testing was conducted during March 1979. Units E and F are part of an intermediate size integrated petroleum refinery located in the North Central United States. Testing was conducted during November 1978. Unit E is an aromatics extraction unit that produces benzene, toluene, and xylene by extraction from refined petroleum feedstocks. Unit E is a new unit and special attention was paid during the design and startup to minimize equipment leaks. All valves were repacked before startup (adding 2 to 3 times the original packing) and all pumps in benzene service had double mechanical seals with a barrier fluid. Unit F produces benzene by hydrodealkylation of toluene. Unit F was originally designed to produce a different chemical and was redesigned to produce benzene.

TABLE C-1. FREQUENCY OF LEAKS FROM FUGITIVE EMISSION SOURCES IN SYNTHETIC ORGANIC CHEMICAL UNITS (Six Unit Study)

Equipment type	Unit A[c] Chloromethanes		Unit B[c] Ethylene		Unit C[d] Chloromethanes		Unit D[e] Ethylene		Unit E[f] BTX Recovery		Unit F[f] Toluene HDA	
	Number of sources tested	Percent with screening values ≥10,000 ppmv	Number of sources tested	Percent with screening values ≥10,000 ppmv	Number of sources tested	Percent with screening values ≥10,000 ppmv	Number of sources tested	Percent with screening values ≥10,000 ppmv	Number of sources tested	Percent with screening values ≥10,000 ppmv	Number of sources tested	Percent with screening values ≥10,000 ppmv
Valves	600	1	2301	19	658	0.1	862	14	715	1.1	427	7.0
Open-ended lines	52	2	386	11	-[a]		90	13	33	0.0	28	11.0
Pump seals	47	15	51	21	39	3	63	33	33[b]	3.0	30	10.0
Compressor seals	-[a]		42	59	3	33	17	6	-[a]		-[a]	
Control valves	52	6	128	20	25	0	25	44	53	4.0	44	11.0
Pressure relief valves	7	0	-[a]		-[a]		-[a]		-[a]		-[a]	
Flanges	30	3	-[a]		-[a]		-[a]		-[a]		-[a]	
Drains	-[a]		-[a]		-[a]		39	10	-[a]		-[a]	

[a] No Data

[b] Pump seals in benzene service have double mechanical seals

[c] Source: Reference 6

[d] Source: Reference 7

[e] Source: Reference 8

[f] Source: Reference 9

C.1.3 Description and Results of an EPA Study of 24 SOCMI Units[10]

The U.S. EPA Industrial Environmental Research Laboratory coordinated a study to develop information about fugitive emissions in the SOCMI. A total of 24 chemical process units were selected for this purpose. The process units were selected to represent a cross section of the population of the SOCMI. Factors considered during process unit selections included annual production volume, number of producers, volatility, toxicity, and value of the final products. Table C-2 shows the process unit types selected for screening.

The screening work began with the definition of the process unit boundaries. All feed streams, reaction/separation facilities, and product and by-product delivery lines were identified on process flow diagrams and in the process unit. Process data, including stream composition, line temperature, and line pressure, were obtained for all flow streams. Each process stream to be screened was identified and process data was obtained with the assistance of plant personnel, in most cases. Sources were screened by a two-person team (one person handling the hydrocarbon detector and one person recording data).

The Century Systems Models OVA-108 and OVA-128 hydrocarbon detectors were used for screening. The HNU Systems, Inc., Model PI 101 Photoionization Analyzer was also used to screen sources at the formaldehyde process unit. The detector probe of the instrument was placed directly on those areas of the sources where leakage would typically occur. For example, gate valves were screened along the circumference of the annular area around the valve stem where the stem exits the packing gland and at the packing gland/valve bonnet interface. All process valves, pump seals, compressor seals, agitator seals, relief valves, process drains, and open-ended lines were screened. From five to twenty percent of all flanges were randomly selected and screened. For the purpose of this program "flange" referred to any pipe-to-pipe or tubing-to-tubing connection, excluding welded joints.

Table C-2. Twenty-four Chemical Process Units Screened for Fugitive Emissions

	Unit Type
1.	Vinyl Acetate
2.	Ethylene
3.	Vinyl Acetate
4.	Ethylene
5.	Cumene
6.	Cumene
7.	Ethylene
8.	Acetone/Phenol
9.	Ethylene Dichloride
10.	Vinyl Chloride Monomer
11.	Formaldehyde
12.	Ethylene Dichloride
13.	Vinyl Chloride Monomer
14.	Methyl Ethyl Ketone
15.	Methyl Ethyl Ketone
16.	Acetaldehyde
17.	Methyl Methacrylate
18.	Adipic Acid
19.	Trichloroethylene/Perchloroethylene
20.	1,1,1-Trichloroethane
21.	Ethylene Dichloride
22.	Adipic Acid
23.	Acrylonitrile
24.	Acrylonitrile

Source: Reference 11

Each screening instrument was calibrated on a daily basis, at a minimum. The model OVA-108 instruments, with a logarithmic scale reading from 1 ppmv to 10,000 ppmv, were calibrated with high (8,000 ppmv) and low (500 ppmv) concentration methane-in-air standards to ensure accurate operation at both ends of the instrument's range. The model OVA-128 instruments, with a linear readout ranging from 0 ppmv to 1,000 ppmv, were also calibrated with high and low concentration standards. A pre-calibrated dilution probe was required with the OVA-128 when calibrating with the 8,000 ppmv standard.

The HNU Photoionization instrument, used to screen the formaldehyde process unit, was calibrated with isobutylene, which has an ionization potential close to that of formaldehyde.

Results of the screening program at the 24 process units are summarized in Table C-3.

The fugitive emission sources in the study were screened at an average rate of 1.7 minutes per source for a two-person team (or 3.4 person-minutes per source). This average screening rate includes time spent for instrument calibration and repair. Table C-4 presents screening time data on a unit-by-unit basis. These time requirements are somewhat higher than would be expected for routine monitoring because of the extensive record keeping associated with the screening project.

C.1.4 Description and Results of Refinery Fugitive Emissions Study[12]

Data concerning the leak frequencies and emission factors for various fugitive sources were obtained primarily at nine refineries. More complete information for compressors and relief valves emissions was obtained by sampling at four additional refineries. Refineries were selected to provide a range of sizes and ages and all of the major petroleum refinery processing units were studied. The type of process units and the number of each studied in the first nine refineries are listed in Table C-5.

TABLE C-3. SUMMARY OF SOCMI PROCESS UNITS FUGITIVE EMISSIONS
(Twenty-four Unit Study)

Source Type	Service	(1) Number Screened	(2) % Not Screened	(3) % of Screened Sources with Screening Values ≥10,000 ppmv	(4) 95% Confidence Interval for Percentage of Sources ≥10,000 ppmv
Flanges	Gas	1,443	4.6	4.6	(3.6, 5.8)
	Light Liquid	2,897	2.6	1.2	(0.9, 1.8)
	Heavy Liquid	607	2.4	0.0	(0.0, 0.6)
Process Drains	Gas	83	23.1	2.4	(0.3, 8.4)
	Light Liquid	527	1.9	3.8	(2.3, 5.8)
	Heavy Liquid	28	0.0	7.1	(0.9, 23.5)
Open Ended Lines	Gas	923	17.5	5.8	(4.4, 7.5)
	Light Liquid	3,603	10.4	3.9	(3.3, 4.6)
	Heavy Liquid	477	21.5	1.3	(0.5, 2.8)
Agitator Seals	Gas	7	46.1	14.3	(0.4, 57.9)
	Light Liquid	8	11.1	0.0	(0.0, 36.9)
	Heavy Liquid	1	66.7	0.0	(0.0, 97.5)
Relief Valves	Gas	85	72.7	3.5	(0.7, 10.0)
	Light Liquid	69	40.5	2.9	(0.3, 10.1)
	Heavy Liquid	3	66.7	0.0	(0.0, 70.8)
Valves	Gas	9,668	17.5	11.4	(10.8, 12.1)
	Light Liquid	18,294	12.2	6.4	(6.1, 6.8)
	Heavy Liquid	3,632	9.9	0.4	(0.2, 0.7)
Pumps	Light Liquid	647	4.3	8.8	(6.6, 11.1)
	Heavy Liquid	97	40.5	2.1	(0.3, 7.3)
Compressors	Gas	29	9.4	6.9	(0.9, 22.8)
Other[a]	Gas	19	9.5	21.0	(6.0, 45.6)
	Light Liquid	33	19.5	6.1	(0.7, 20.2)
	Heavy Liquid	2	33.3	0.0	(0.0, 84.2)

[a] Includes filters, vacuum breakers, expansion joints, rupture disks, sight glass seals, etc.
Source: Ref. 13

TABLE C-4. AVERAGE FUGITIVE EMISSION SOURCE SCREENING RATES (Twenty-four Unit Study)

Process Unit Type	Number of Screened Sources	Average Screening Time Per Source, Minutes[a]
1. Vinyl Acetate	1,391	2.0
2. Ethylene	5,078	1.3
3. Vinyl Acetate	2,780	0.9
4. Ethylene	5,278	1.5
5. Cumene	1,025	0.9
6. Cumene	1,573	1.0
7. Ethylene	3,685	1.9
8. Acetone/Phenol	3,207	3.2
9. Ethylene Dichloride	1,430	
10. Vinyl Chloride Monomer	868	2.6
11. Formaldehyde	230	1.8
12. Ethylene Dichloride	744	1.6
13. Vinyl Chloride Monomer	2,619	
14. Methyl Ethyl Ketone	585	1.6
15. Methyl Ethyl Ketone	679	2.2
16. Acetaldehyde	1,148	1.2
17. Methyl Methacrylate	2,019	0.9
18. Adipic Acid	1,577	0.7
19. Tricholoroethylene/Perchloroethylene	2,720	
20. 1,1,1-Trichloroethane	570	1.6
21. Ethylene Dichloride	42	
22. Adipic Acid	664	1.9
23. Acrylonitrile	1,406	2.5
24. Acrylonitrile	1,864	1.9
Total	43,182	1.7

[a] Average source screening time was determined for a two-person team, one person screening with a portable hydrocarbon detector and one person recording data. Average screening time includes time spent for instrument calibration, maintenance, and repair.

Source: Ref. 14

TABLE C-5. SAMPLED PROCESS UNITS FROM NINE REFINERIES DURING REFINERY STUDY

Refinery process unit	Number of sampled units
Atmospheric distillation	7
Vacuum distillation	4
Thermal operations (coking)	2
Catalytic cracking	5
Catalytic reforming	6
Catalytic hydrocracking	2
Catalytic hydrorefining	2
Catalytic hydrotreating	7
Alkylation	6
Aromatics/isomerization	3
Lube oil manufacture	2
Asphalt manufacture	1
Fuel gas/light-ends processing	11
LPG	2
Sulfur recovery	1
Other	3

Source: Ref. 15

In each refinery, sources in six to nine process units were selected for study. The approximate number of sources selected for study and testing in each refinery is listed below:

Valves	250-300
Flanges	100-750
Pump seals	100-125
Compressor seals	10-20
Drains	20-40
Relief Valves	20-40

There were normally 500-600 sources selected in each refinery.

The distribution of sources among the process units was determined before the selection and testing of individual sources was begun. Individual sources were selected from piping and instrumentation diagrams or process flow diagrams before a refinery processing area was entered. Only those preselected sources were screened. In this way, bias based on observation of individual sources was theoretically eliminated.

The screening of sources was accomplished with portable organic vapor detectors. The principal device used in this study was the J. W. Bacharach Instrument Co. "TLV Sniffer" calibrated with Hexane. The components were tested on an individual basis and only those components with VOC concentrations in excess of 200 ppmv were considered for further study.

A substantial portion of these leaking sources were enclosed and sampled to determine both the methane and nonmethane emission rates. An important result of this program was the development of a correlation between the maximum observed screening value (VOC concentration) and the measured nonmethane leak rate.

Emission factors and leak frequency information generated during this study are given in Table C-6.

C.1.5 Comparison of Fugitive Emissions Test Data from Refineries and SOCMI Units

The results of the SOCMI studies and those of the refinery emissions study are compared in Table C-7.

TABLE C-6. LEAK FREQUENCIES AND EMISSION FACTORS FROM FUGITIVE SOURCES IN PETROLEUM REFINERIES

Equipment type	Percent of sources having screening values ≥10,000 ppmv TLV-Hexane	Estimated emission factor for refinery sources, kg/hr-source
Valves	NA	NA
Gas service	10	0.021
Light liquid service	12	0.010
Heavy liquid service	0	0.0003
Pump seals	NA	NA
Light liquid service	23	0.12
Heavy liquid service	2	0.02
Compressor seals (hydrocarbon service)	33	0.44
Pressure relief valves	8	0.086
Gas service		0.16
Light liquid service		0.006
Heavy liquid service		0.009
Flanges	0	0.0003
Open-ended lines	NA	NA
Gas service		0.025
Light liquid service		0.014
Heavy liquid service		0.003

Source: Ref. 17

TABLE C-7. COMPARISON OF LEAK FREQUENCIES FOR FUGITIVE EMISSION SOURCES IN SOCMI UNITS AND PETROLEUM REFINERIES

Equipment Type	Percent of SOCMI Sources Having Screening Values ≥10,000 ppmv, OVA-108, Methane (six unit study)[a]	Percent of SOCMI Sources Having Screening Values ≥10,000 ppmv, OVA-108 Methane(24 unit study)[b]	Percent of Petroleum Refinery Sources Having ≥Screening Values 10,000 ppmv, TLV - Hexane[c]
Valves (all)	11		
Gas		11.4	10
Light Liquid		6.4	12
Heavy Liquid		0.4	0
Open-ended lines (all)	10		N/A
Gas		5.8	
Light Liquid		3.9	
Heavy Liquid		1.3	
Pumps (all)	17		
Light Liquid		8.8	23
Heavy Liquid		2.1	2
Compressors (Gas)	43	6.9	33
Pressure Relief Valves (all)	0		8
Gas		3.5	N/A
Light Liquid		2.9	N/A
Heavy Liquid		0.0	N/A
Flanges (all)	3		0
Gas		4.6	
Light Liquid		1.2	
Heavy Liquid		0.0	
Process Drains (all)	N/A		N/A
Gas		2.4	
Light Liquid		3.8	
Heavy Liquid		7.1	
Agitator Seals (all)	N/A		N/A
Gas		14.3	
Light Liquid		0.0	
Heavy Liquid		0.0	
Other	N/A		N/A

[a] Source: Ref. 18, 19, 20, 21

[b] Source: Ref. 22

[c] Source: Ref. 23.

[d] Includes filters, vacuum breakers, expension joints, rupture disks, sight glass seals, etc.

C.1.6 Description and Results of the DuPont Study[16]

DuPont conducted a program of fugitive emission measurement from pumps and valves at two of their plants. The processes of the 5 and 10 year old plants were not revealed. The OVA-108 was used for screening (leak identification) and for leak rate determination (analysis of collected leak vapors). The leak rate was determined by taking Tedlar bags partially filled with air and enclosing the leaking valve. The hydrocarbon concentration in the bags was recorded as a function of time. Visual estimates of the initial bag volume were assumed to be ±5 percent. Dupont did not have a dilution probe and, therefore, measurements above 10,000 ppm were not made. Analysis of the data collected indicates that no significant difference in leak rates exists between manual and automatic control valves. Significant trends were observed with changes in product vapor pressure. It also seemed that full open or closed valve seat positions resulted in lower leak rates than intermediate positions. The results of the DuPont study are shown in Table C-8.

C.1.7 Description and Results of the Exxon Study[24,25]

A fugitive emissions study was conducted by Exxon Chemical Company at the Cyclohexane unit at their Baytown plant. The total number of valves, pumps and compressor seals, and safety valves were determined. For all sources, except valves, all of the fugitive emission sources were sampled. For valves, a soap solution was used to determine leaking components. All leaking valves were counted and identified as either small, medium or large leaks. From the set of valves found to be leaking, specific valves were selected for sampling so that each class of leaking valves was in approximately the same proportion as it occured in the cyclohexane unit.

Heat resistant mylar bags or sheets were taped around the equipment to be sampled to provide an enclosed volume. Clean metered air from the filter apparatus was blown into the enclosed volume. The sampling train was allowed to run until a steady state flow was obtained (usually about 15 minutes). A bomb sample was then taken for laboratory analysis (mass spectrometry). Table C-9 presents the results of the Exxon study.

TABLE C-8. FREQUENCY OF LEAKS[a] FROM FUGITIVE EMISSION SOURCES IN TWO DuPONT PLANTS.

Equipment type	No. of leakers	No. of non-leakers	Percent leakers
Valves	48	741	6.1
Gas	35	120	23.1
Light liquid	11	143	7.1
Heavy liquid	1	478	0.2
Pumps	1	36	2.7
Light liquid	1	6	14.3
Heavy liquid	0	29	0

[a] Leak defined as 10,000 ppm or greater.
Source: Ref. 26

TABLE C-9. FREQUENCY OF LEAKS[a] FROM FUGITIVE EMISSION SOURCES IN EXXON'S CYCLOHEXANE UNIT

Equipment Source	Total in Unit	Screened and Sampled	Percent Leaking	Emission factor(kg/hr)	99.8% Confidence Interval (kg/hr)
Valves					
Gas	136	136	32	0.017	0.008 - 0.035
light liquid	201	100	15	0.008	0.003 - 0.007
Safety valves	15	15	87	0.064	0.013 - 0.5
Pump seals[b]	8	8	83	0.255	0.082 - 0.818
Compressor seals[b]	N/A	N/A	100	0.264	0.068 - 1.045

N/A - Not available

[a] Leak defined as 10,000 ppm or greater.

[b] Double mechanical seal pumps and compressors were found to have negligible leaks.

Source: Reference 27,28

C.2 MAINTENANCE TEST PROGRAMS

The results of four studies on the effects of maintenance on fugitive emissions from valves are discussed in this section. The first two studies were conducted by refinery personnel at the Union Oil Co. refinery in Rodeo, California, and the Shell Oil Co. refinery in Martinex, California. These programs consisted of maintenance on leaking valves containing fluids with vapor pressures greater than 1.5 Reid Vapor Pressure. The third study was conducted by EPA. Valves were selected and maintained at four refineries. The fourth study was conducted by EPA at Unit D (ethylene unit). The study results and a description of each test program are given in the following sections.

C.2.1 Description and Results of the Union Maintenance Study[29]

The Union valve maintenance study consisted of performing undirected maintenance on valves selected from 12 different process units. Maintenance procedures consisted of adjusting the packing gland while the valve was in service. Undirected maintenance consists of performing valve repairs without simultaneous measurement of the effect of repair on the VOC concentration detected. This is in contrast to directed maintenace where emissions are monitored during the repair procedure. With directed maintenance, repair procedures are continued until the VOC concentration detected drops to a specified level or further reduction in the emission level is not possible. Also, maintenance may be curtailed if increasing VOC concentrations result.

The Union data was obtained with a Century Systems Corporation Organic Vapor Analyzer, OVA-108. All measurements were taken at a distance of 1 cm from the seal. Correlations developed by EPA have been used to convert the data from OVA readings taken at one centimeter to equivalent TLV readings at the leak interface (TLV-0).[30] This facilitates comparison of data from different studies and allows the estimation of emission rates based on screening values-leak rate correlations.

The results of the Union study are given in Table C-10. Two sets of results are provided; the first includes all reparied valves with before maintenance screening values greater than or equal to 5,300 ppmv

TABLE C-10. SUMMARY OF MAINTENANCE STUDY RESULTS FROM THE UNION OIL CO. REFINERY IN RODEO, CALIFORNIA[a]

	All valves with initial screening values ≥5300 ppmv[b]	All valves with initial screening values <5300 ppmv
Number of repairs attempted	133	21
Estimated emissions before maintenance, kg/hr[c]	9.72	0.323
Estimated emissions after maintenance, kg/hr[c]	4.69	0.422
Number of successful repairs (<5300 ppmv after maintenance)	67	--
Number of valves with decreased emissions	124	13
Number of valves with increased emissions	9	8
Percent reduction in emissions	51.8	-30.5
Percent successful repairs	50.4	--
Percent of valves with decreased emissions	93.2	61.9
Percent of valves with increased emissions	6.8	38.1

[a] Source: Ref. 33.

[b] The value 5300 ppmv, taken with the OVA-108 at 1 cm., generally corresponds to a value of 10,000 ppmv taken with a "TLV Sniffer" at 0 cm.

(OVA-108), and the second includes valves with before maintenance screening values below 5,300 ppmv (OVA-108). A screening value of 5,300 ppmv, obtained with OVA at 1 cm from the leak interface, is equivalent to a screening value of 10,000 ppmv measured by a Bacharach Instrument Co. "TLV Sniffer" directly at the leak interface. The OVA-1 cm readings have been converted to equivalent TLV-0 cm readings because:

1) EPA correlations which estimate leak rates from screening values were developed from TLV-0 cm data.

2) Additional maintenance study data exists in the TLV-0 cm format.

3) Method 21 specifies 0 cm screening procedures.

The results of this study indicate that maintenance on valves with initial screening values above 10,000 ppmv (OVA-108) is much more effective than maintenance on valves leaking at lower rates. In fact, this study indicates that emissions from valves are reduced by an average of 51.8 percent for valves initially over 5,300 ppmv while valves with lower initial screening values experienced an increase of 30.5 percent.

C.2.2 Description and Results of the Shell Maintenance Study[31]

The Shell maintenance program consisted of two parts. First, valve repairs were performed on 171 leaking valves. In the second part of the program, 162 of these valves were rechecked and additional maintenance was performed. Maintenance consisted of adjusting the packing gland while the valve was in service. The second part of the program was conducted approximately one month after the initial maintenance period. It was not determined whether the maintenance procedures were directed or undirected, based on the information reported by Shell.

VOC emissions were measured using the OVA-108 and readings were obtained one centimeter from the source. This data has been transformed to TLV-0 cm values as was the Union data. And, the same methods of data analysis described in Section C.2.1 have been applied to the Shell data. The results of the Shell maintenance study are given in Table C-11.

TABLE C-11. SUMMARY OF MAINTENANCE STUDY RESULTS FROM THE SHELL OIL COMPANY REFINERY IN MARTINEZ, CALIFORNIA

	March maintenance		April maintenance	
	All repaired valves with initial screening values ≥5300 ppmv[b]	All repaired valves with initial screening values <5300 ppmv	All repaired valves with initial (March) screening values ≥5300 ppmv	All repaired valves with initial (March) screening <values 5300 ppmv
Number of repairs attempted	161	11	152[d]	11[e]
Estimated emissions before maintenance, kg/hr[c]	11.08	0.159	2.95	0.060
Estimated emissions after maintenance, kg/hr[c]	2.66	0.0	0.421	0.0
Number of successful repairs (<5300 ppmv after maintenance)	105	--	45	--
Number of valves with decreased emissions	161	11	151	11
Number of valves with increased emissions	0	0	1	0
Percent reduction in emissions	76.0	100.0	85.7	100.0
Percent successful repairs	65.2	--	83.3	--
Percent of valves with decreased emissions	100.0	100.0	99.3	100.0
Percent of valves with increased emissions	0.0	0.0	0.7	0.0

[a] Source: Ref. 34.

[b] The value 5300 ppmv, taken with the OVA-108 at 1 cm., generally corresponds to a value of 10,000 ppmv taken with a "TLV Sniffer" at 0 cm.

[c] Shell reported the screening value of all valves which measured <3000 ppmv (<1500 ppmv-TLV at 0 cm.) as non-leakers. Emissions estimates obtained from emission factors. Ref. 14.

[d] Initial value of 90 of these valves was <1500 ppm-TLV at 0 cm., 54 valves screened ≥5300 (note nine valves from initial data set not rechecked in April).

[e] Initial value of 10 of these valves was <1500 ppm-TLV at 0.cm.

C.2.3 Description and Results of the EPA Maintenance Study[32]

Repair data were collected on valves located in four refineries. The effects of both directed and undirected maintenance were evaluated. Maintenance consisted of routine operations, such as tightening the packing gland or adding grease. Other data, including valve size and type and the processes' fluid characteristics, were obtained. Screening data were obtained with the Bacharach Instrument Company. "TLV Sniffer" and readings were taken as close to the source as possible.

Unlike the Shell and Union studies, emission rates were not based on the screening value correlations. Rather, each valve was sampled to determine emission rates before and after maintenance using techniques developed by EPA during the refinery emission factor study. These values were used to evaluate emissions reduction.

The results of this study are given in Table C-12. Of interest here is a comparison of the emissions reduction for directed and undirected maintenance. The results indicate that directed maintenance is more effective in reducing emissions than is undirected maintenance, particularly for valves with lower initial leak rates. The results showed an increase in total emissions of 32.6% for valves with initial screening values less than 10,000 ppmv which were subjected to undirected maintenance. However, this increase is due to a large increase in the emission rate of only one valve.

C.2.4 Description and Results of Unit D (Ethylene Unit) Maintenance Study[35]

Maintenance was performed by Unit D personnel. VOC concentration measurements were made using the OVA-108, and readings were obtained at the closest distance possible to the source. The results of this study are shown in Table C-13. Directed and undirected maintenance procedures were used. The results show that directed maintenance results in more repairs being successfully completed than when undirected maintenance is used.

C.2.5 Comparison of Maintenance Study Results

Generally speaking, the results of these maintenance programs would tend to support the following conclusions:

TABLE C-12. SUMMARY OF EPA REFINERY MAINTENANCE STUDY RESULTS

	Repaired values with initial screening values ≥10,000 ppmv		Repaired values with initial screening values <10,000 ppmv	
	Directed Maintenance	Undirected Maintenance	Directed Maintenance	Undirected Maintenance
Number of valves repaired	9	23	10	16
Measured emissions before maintenance kg/hr	0.107	1.809	0.0332	0.120
Measured emissions after maintenance kg/hr	0.0139	0.318	0.0049	0.159
Number of successful repairs (<10,000 ppmv after maintenance)	8	13	-	-
Number of valves with decreased emissions	9	21	6	15
Number of valves with increased emissions	0	2	4	1
Percent reduction in emissions	87.0	82.4	85.2	-32.6
Percent successful repairs	88.9	56.5	-	-
Percent of valves with decreased emissions	100.0	91.3	60.0	93.8
Percent of valves with increased emissions	0.0	8.7	40.0	6.3

Source: Ref.36

TABLE C-13. MAINTENANCE EFFECTIVENESS
UNIT D ETHYLENE UNIT BLOCK VALVES

1. Total number of valves with VOC >10,000 ppm from unit survey	121	
2. Total number of valves tested for maintenance effectiveness	46	
% Tested		38%
UNDIRECTED MAINTENANCE		
3. Total number subjected to repair attempts	37	
4. Successful repairs (VOC < 10,000 ppm)	22	
% Repaired		59%
Followup DIRECTED MAINTENANCE		
5. Number of valves unrepaired by undirected maintenance subjected to directed maintenance	14	
6. Number repaired by followup directed maintenance	5	
% of unsuccessful repaired by directed maintenance		36%
7. Total number repaired based on undirected maintenance subset (3) above	27	
% Repaired		73%
8. Total number of repairs including leaks not found before initial maintenance	29	
Total % repaired		63%
Total % not repaired		37%

Source: Reference 37

- A reduction in emissions may be obtained by performing maintenance on valves with screening values above 10,000 ppmv (measured at the source).
- The reduction in emissions due to maintenance of valves with screening values below 10,000 ppmv is not as dramatic and may result in increased emissions.
- Directed maintenance is preferable to undirected maintenance for valve repair.

The information presented in Tables C-10, C-11, C-12, and C-13 has been compiled with the objective of placing the data on as consistent a basis as possible. However, some differences were unavoidable and others may have gone unrecognized, due to the limited amount of information concerning the details of methods used in each study. Therefore, care should be exercised before attempting to draw specific quantitative conclusions based on direct comparison of the results of these studies.

C.3 REFERENCES

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APPENDIX D - EMISSION MEASUREMENT AND CONTINUOUS MONITORING

D.1 EMISSION MEASUREMENT METHODS

To develop data in support of standards for the control of fugitive emissions, EPA conducted leak surveys at six petroleum refineries and three synthetic organic chemical manufacturing plants. The resulting leak determination procedures contained in Reference Method 21 were developed during the course of this test program.

Prior to the first test, available methods for measurement of fugitive leaks were reviewed, with emphasis on methods that would provide data on emission rates from each source. To measure emission rates, each individual piece of equipment must be enclosed in a temporary cover for emission containment. After containment, the leak rate can be determined using concentration change and flow measurements. This procedure has been used in several studies,[1,2] and has been demonstrated to be a feasible method for research purposes. It was not selected for this study because direct measurement of emission rates from leaks is a time-consuming and expensive procedure requiring about $40 and 2 manhours per source.[3] It is not feasible or practical for routine testing because of the large number of sources within each process unit. There can be more than 2000 valves in light liquid and gas service in a process unit.

Procedures that yield qualitative or semi-quantitative indications of leak rates were then reviewed. There are essentially two alternatives: leak detection by spraying each component leak source with a soap solution and observing whether or not bubbles were formed; and, the use of a portable analyzer to survey for the presence of increased organic compound concentration in the vicinity of a leak source. Visual, audible, or olfactory inspections are too subjective to be used as indicators of leakage in these applications. The use of a portable analyzer was selected as a basis for the method because it would have been difficult to establish a leak definition based on bubble formation rates. Also, the temperature of the component, physical configuration, and relative movement of parts often interfere with bubble formation.

Once the basic detection principle was selected, it was then necessary to define the procedures for use of the portable analyzer. Prior to performance of the first field test, a procedure was reported that conducted surveys at a distance of 5 cm from the components.[4] This information was used to formulate the test plant for initial testing.[5] In addition, measurements were made at distances of 25 cm and 40 cm on three perpendicular lines around individual sources. Of the three distances, the most repeatable indicator of the presence of a leak was a measurement at 5 cm, with a leak definition concentration of 100 or 1000 ppmv. The localized meteorological conditions affected dispersion significantly at greater distances. Also it was difficult to define a leak at greater distances because of the small changes from ambient concentrations observed. Surveys were conducted at 5 cm from the source during the next three facility tests.

The procedure was distributed for comment in a draft control techniques guideline documents.[6] Many commentors felt that a measurement distance of 5 cm could not be accurately repeated during screening tests. Since the concentration profile is rapidly changing between 0 and about 10 cm from the source, a small variance from 5 cm could significantly effect the concentration measurement. In response to these comments, the procedures were changed so that measurements were made at the surface of the interface, or essentially 0 cm. This change required that the leak definition level be increased. Additional testing at two refineries and three chemical plants was performed by measuring volatile organic concentrations at the interface surface.

A complication that this change introduces is that a very small mass emission rate leak ("pin-hole leak") can be totally captured by the instrument and a high concentration result will be obtained. This has occurred occasionally in EPA tests and a solution to this problem has not been found.

The calibration basis for the analyzer was evaluated. It was recognized that there are a number of potential vapor stream components and compositions that can be expected. Since all analyzer types do not respond equally to different compounds, it was necessary to establish a reference calibration material. Based on the expected compounds and the limited information available on instrument response factors, hexane was chosen as the reference calibration gas for EPA test programs. At the 5 cm measurement distance, calibrations were conducted at approximately 100 or 1000 ppmv levels. After the measurement distance was changed, calibrations at 10,000 ppmv levels were required. Comments received indicated that hexane standards at this concentration were not readily available commercially. Consequently, modifications were incorporated to allow alternate standard preparation procedures or alternate calibration gases in the test method recommended in the Control Techniques Guideline Document for Petroleum Refinery Fugitive Emissions. Since that time, additional studies have begun to develop response factor data for two instrument types. Based on preliminary results, it appears that methane is a more representative reference calibration material at 10,000 ppmv levels. Based on this conclusion, and the fact that methane standards are readily available at the necessary calibration concentration, the recommended calibration material for this regulation was changed to methane.

The alternative of specifying a different calibration material for each type stream and normalization factors for each instrument type was not intensively investigated. There are at least four instrument types available that might be used in this procedure, and there are a large number of potential stream compositions possible. The amount of prior knowledge necessary to develop and subsequently use such factors would make the interpretation of results prohibitively complicated. Based on EPA test results, the number of concentration measurements in the range where a variability of two or three would change the decision as to whether or not a leak exists is small in comparison to the total number of potential leak sources.

An alternative approach to leak detection was evaluated by EPA during field testing. The approach used was an area survey, or walkthrough, using a portable analyzer. The unit area was surveyed by walking through the unit positioning the instrument probe within 1 meter of all valves and pumps. The concentration readings were recorded on a portable strip chart recorder. After completion of the walkthrough, the local wind conditions were used with the chart data to locate the approximate source of any increased ambient concentrations. This procedure was found to yield mixed results. In some cases, the majority of leaks located by individual component testing could be located by walkthrough surveys. In other tests, prevailing dispersion conditions and local elevated ambient concentrations complicated or prevented the interpretation of the results. Additionally, it was not possible to develop a general criteria specifying how much of an ambient increase at a distance of 1 meter is indicative of a 10000 ppm concentration at the leak source. Because of the potential variability in results from site to site, routine walkthrough surveys were not selected as a reference or alternate test procedure.

D.2 CONTINUOUS MONITORING SYSTEMS AND DEVICES

Since the leak determination procedure is not a typical emission measurement technique, there are no continuous monitoring approaches that are directly applicable. Continual surveillance is achieved by repeated monitoring or screening of all affected potential leak sources. A continuous monitoring system or device could serve as an indicator that a leak has developed between inspection intervals. EPA performed a limited evaluation of fixed-point monitoring systems for their effectiveness in leak detection. The systems consisted of both remote sensing devices with a central readout and a central analyzer system (gas chromatograph) with remotely collected samples. The results of these tests indicated that fixed point systems were not capable of sensing all leaks that were found by individual component testing. This is to be expected since these systems are significantly affected by local dispersion conditions and would require either many individual point locations, or very low detection sensitivities in order to achieve similar results to those obtained using an individual component survey.

It is recommended that fixed-point monitoring systems not be required since general specifications cannot be formulated to assure equivalent results, and each installation would have to be evaluated individually.

D.3 PERFORMANCE TEST METHOD

The recommended fugitive emission detection procedure is Reference Method 21. This method incorporates the use of a portable analyzer to detect the presence of volatile organic vapors at the surface of the interface where direct leakage to atmosphere could occur. The approach of this technique assumes that if an organic leak exists, there will be an increased vapor concentration in the vincinity of the leak, and that the measured concentration is generally proportional to the mass emission rate of the organic compound.

An additional procedure provided in Reference Method 21 is for the determination of "no detectable emissions". The portable VOC analyzer is used to determine the local ambient VOC concentration in the vincinity of the source to be evaluated, and then a measurement is made at the surface of the potential leak interface. If a concentration change of less than 2 percent of the leak definition is observed, then a "no detectable emissions" condition exists. The definition of 2 percent of the leak definition was selected based on the readability of a meter scale graduated in 2 percent increments from 0 to 100 percent of scale, and not necessarily on the performance of emission sources. "No detectable emissions" would exist when the observed concentration change between local ambient and leak interface surface measurements is less than 200 ppmv.

Reference Method 21 does not include a specification of the instrument calibration basis or a definition of a leak in terms of concentration. Based on the results of EPA field tests and laboratory studies, methane is recommended as the reference calibration basis for fugitive emission sources in synthetic organic chemical manufacturing industries.

There are at least four types of detection principles currently available in commercial portable instruments. These are flame ionization, catalytic oxidation, infrared absorption (NDIR), and photoionization. Two types (flame ionization and catalytic oxidation) are known to be available in factory mutual certified versions for use in hazardous atmospheres.

The recommended test procedure includes a set of design and operating specifications and evaluation procedures by which an analyzer's performance can be evaluated. These parameters were selected based on the allowable tolerances for data collection, and not on EPA evaluations of the performance of individual instruments. Based on manufacturers' literature specifications and reported test results,[7] commercially available analyzers can meet these requirements.

The estimated purchase cost for an analyzer ranges from about $1,000 to $5,000 depending on the type and optional equipment. The cost of an annual monitoring program per unit, including semiannual instrument tests and reporting is estimated to be from $3,000 to $4,500. This estimate is based on EPA contractor costs experienced during previous test programs. Performance of monitoring by plant personnel may result in lower costs. The above estimates do not include any costs associated with leak repair after detection.

D.4 REFERENCES

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APPENDIX E. METHODOLOGY FOR ECONOMIC ANALYSIS

APPENDIX E: METHODOLOGY FOR COMPUTING COST OF CAPITAL TO SYNTHETIC ORGANIC CHEMICAL MANUFACTURERS

This appendix describes the process used to estimate the cost of capital for the chemical industry. The cost of capital for any new project is the cost of equity, debt, and preferred stock, weighted by the percentage of funds generated by each type of financing; that is,

$$k_c = k_e \frac{E}{I} + k_i \frac{D}{I} + k_p \frac{P}{I} \qquad (1)$$

where

k_c ≡ cost of capital,

k_e ≡ cost of equity capital,

k_i ≡ cost of debt capital,

k_p ≡ cost of preferred stock capital,

E ≡ the amount of equity used to finance a given investment,

D ≡ the amount of debt used to finance a given investment,

P ≡ the amount of preferred stock used to finance a given investment,

I ≡ the total funds needed for the investment.

The k variables are interest rates representing the aftertax return on investment that is needed to pay stock dividends and interest on debt. Each k term is a nominal interest rate in that it contains an implicit allowance for inflation. However, the cost of capital computed with equation (1) is treated in the text as the real dollar interest rate that would prevail in times of economic stability. The nominal rate is used as though it were a real rate partly to ensure that estimates of the cost and other adverse economic effects of investment in air pollution controls will be biased upward rather than downward, and partly to avoid miscalculations that could result from using the wrong inflation rate to convert the nominal rate to a real rate.

The first step in estimating equation (1) is to determine the relevant weights for the three types of financing. It is assumed that the proportion of debt, equity, and preferred stock to be used on any new project will be the same as currently exists in the firm's capital structure. This implies that the firm is currently using the optimal mix of financing. Figures for the three types of funds came from the COMPUSTAT tapes, supplied by Standard & Poor's Corporation, for each firm's fiscal year ending in 1977. Common equity included the par value of common stock, retained earnings, capital surplus, self-insurance reserves, and capital premium, while debt included all obligations due more than a year from the company's balance sheet date. Preferred stock represented the net number of preferred shares outstanding at year-end multiplied by the involuntary liquidating value per share.

The next step in calculating equation (1) is to estimate the cost of equity financing. Two approaches are commonly used: the results derived from the capital-asset pricing model (CAPM) and the results derived from the dividend capitalization model (DCM). The CAPM compares the returns from a firm's stock with those from the stock market as a whole, while the DCM evaluates the stream of dividends and the discount rate needed to arrive at the firm's existing share price. The required return on equity using the CAPM is:

$$k_e = i + \beta (k_m - i) \tag{2}$$

where

$i \equiv$ the expected risk-free interest rate,

$k_m - i \equiv$ the expected excess return on the market, and

$\beta \equiv$ the firm's beta coefficient.

The beta coefficient is an historical measure of the extent to which a firm's stock price fluctuates in relation to an index of the stock market as a whole. β takes on a value of zero for a stock whose price is constant, a value of one for a stock whose price follows the same path as an index of the whole stock market, and a value of greater than (less than) one for a stock whose price fluctuates more (less) dramatically than does the general index. The CAPM is thus a modified regression equation in which β is the slope of a straight line relating k_e and k_m.

The required return on equity using the DCM is:

$$k_e = \frac{D_1}{P_o} + g \qquad (3)$$

where

D_1 ≡ the dividend expected in period 1,

P_o ≡ the share price at the beginning of period 1,

g ≡ the expected rate of dividend growth, assumed to be constant.

The DCM is developed on the assumptions that (1) the price of a stock is the present value of anticipated dividends, and that (2) these dividends grow each year by a fixed percentage that is less than the required return on equity.

Figures for equation (2) were developed in the following manner. The expected risk-free rate was assumed equal to the yield on a 3-month Treasury Bill, as reported in the October 1, 1979, Wall Street Journal. The current yield was 10.46 percent. This corresponds to the yield from a bond with no possibility of default and offering no chance of a capital loss and is therefore riskless. The firm's beta coefficients came from the September 24, 1979, Value Line Investment Survey. The expected excess return equalled 2.9646 percent, the 5-year average (July 1974-June 1979) of the monthly excess returns on the Standard & Poor's 500 Stock Index multiplied by twelve.

Figures for equation (3) came from two sources. Both share price and expected yearly dividends came from figures reported in the October 1, 1979, Wall Street Journal. The growth rate was calculated from data contained on the COMPUSTAT tapes. Note that the use of historical data does not necessarily make the estimated rate of return on capital inconsistent with the first quarter 1980 cost data used in this study as both short- and long-term interest rates are currently in a state of flux. Three different growth rates were examined: the 5-year average growth of total assets, the 5-year average growth of per share earnings, and the 5-year average growth of dividends.

A number of theoretical reasons exist for preferring the CAPM approach to the DCM for estimating the required return on equity, but the figures calculated revealed a more practical justification. Using growth estimated from per share earnings or dividends resulted in a number of firms having negative required returns with the DCM method. Although using the growth in assets resulted in only one firm with a negative required return, several firms had extremely low returns (less than 10 percent). It is unreasonable to expect that stockholders would demand a return on their stock that is less than the existing yield on Treasury Bills, yet all three variants of the DCM method led to this conclusion for a number of firms. On the basis of these considerations the CAPM calculations were selected as the required return on equity.

The third step in estimating equation (1) is calculating the cost of debt financing. This would be a relatively easy estimation if interest rates did not change over time. Past yields on old issues of bonds would suffice. Since interest rates have been fluctuating, it was felt that a more forward-looking rate was required. The method selected was to take the average yield as given in the September 3, 1979, Moody's Bond Survey for the firm's bond ratings class as the necessary yield the firm must offer on long-term debt. The firm's ratings class came from the September 1979 Moody's Bond Record or the 1979 Moody's Industrial Manual. A small number of firms were not rated by Moody's. One firm was ranked in Standard and Poor's Bond Guide and this was used to approximate a Moody's bond class. For other firms, data concerning bank notes, revolving credit, or term-loan agreements that tied the interest rate on these types of debt to the current prime rate were obtained from the 1979 Moody's Industrial Manual or the Standard & Poor's Corporation Record. These data were taken to measure the necessary yield on long-term debt for such firms. Table E-1 presents the yields by ratings class and the prime rate (as of October 1, 1979) used for the cost of debt funds.

The yield on long-term debt does not represent the aftertax cost of debt financing since interest charges are tax deductable. To arrive at the aftertax cost of debt capital, the yield must be multiplied by 1 minus the marginal tax rate.

TABLE E-1. YIELDS BY RATING CLASS FOR COST OF DEBT FUNDS, 1979
(Prime rate = 13.50 %)

Ratings class	Yield (percent)
AAA	9.25
AA	9.59
A	9.72
BAA	10.38
BA	11.97
B	12.395

$$k_i = k(1 - t) \tag{4}$$

where

$k \equiv$ the yield on bonds,

$t \equiv$ the marginal tax rate.

It is assumed that the firms in the sample are profitable so that taxes must be paid, and that their marginal tax rate is 48 percent.

The last step in estimating equation (1) is to calculate the cost of preferred stock financing. Unlike debt, preferred stock does not have a maturity date so that the current yield should approximate the yield on new issues. The yield is:

$$k_p = \frac{D}{P} \tag{5}$$

where

$D =$ stated annual dividend,

$P =$ the price of a share of preferred stock.*

The figures for dividends and share price came from the October 1, 1979, Wall Street Journal or, if not included in this source, from the January 1, 1979, listing in the Daily Stock Price Record. A number of firms did not have their preferred stock listed in either source, yet had preferred stock in their capital structures. All used less than 15 percent preferred stock, with the majority using less than 5 percent. For these firms the aftertax yield on preferred stock was set equal to the pretax yield on long-term debt.

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*Note that as preferred stock dividends do not increase over time the growth factor required in the discounted cash flow model (equation 3) is omitted here.

Table E-2 lists the cost of capital for all 100 firms in the sample and also includes some of the components of equation (1). These firms represent the best available sample of the approximately 600 firms in the industry. However, it is likely that on the average the firms included in the sample are larger than the firms excluded, as many small firms do not have to publish detailed financial records. This potential sample bias may have resulted in a slight underestimate of the industry's cost of capital as, in general, because they are (usually) able to reduce their transactions costs of borrowing and to represent a less risky investment because of product diversification, larger firms are often able to acquire investment funds more cheaply than smaller firms.

TABLE E-2. FINANCIAL DATA FOR 100 CHEMICAL FIRMS[1] 11

Name	Cost of capital	Return on equity	Return on debt[a]	Return on preferred stock[b]	Proportion of equity	Proportion of debt	Proportion of preferred stock
Abbott Labs	12.014	14.018	9.590	--	.77262	.216575	.010804
Akzona	10.276	13.276	10.380	--	.61914	.380859	.000
Alco Standard Corp.	12.151	13.425	15.120	--	.64134	.259343	.099317
Allied Chem Corp.	10.091	13.721	9.720	--	.58118	.418825	.000
American Cyanamid	11.083	13.425	9.590	--	.72252	.277480	.000
Armco Steel Corp.	10.588	13.276	9.720	6.461	.66880	.306858	.024337
Atlantic Richfield	9.749	13.128	9.590	--	.51602	.362174	.121802
Beatrice Foods	11.232	12.832	9.250	7.429	.79803	.194329	.007644
Bendix Corp.	11.118	13.425	9.720	3.333	.72911	.248140	.022754
Bethlehem Steel Corp.	10.913	14.018	9.720	--	.65360	.346402	.000
Borden Inc.	10.484	12.683	9.590	--	.71317	.285155	.001677
Borg-Warner Chem.	11.863	13.128	9.720	--	.82756	.145263	.027181
Brown Co.	9.813	12.387	12.395	--	.56680	.433202	.000
CPC International Inc.	11.638	13.128	9.590	--	.81691	.183087	.000
Celanese Corp.	10.181	13.128	11.970	10.084	.53511	.396896	.067997
Charter International Oil	9.175	14.166	12.395	--	.27557	.623167	.101265
Cities Service Co.	10.395	12.980	9.720	--	.67388	.326120	.000
Combustion Engineering	11.494	14.314	9.720	--	.68700	.296229	.016774
Continental Oil	10.881	13.721	9.590	2.564	.67568	.321308	.003009
Crompton & Knowles	11.298	13.425	14.450	--	.53329	.375634	.091078
Dart Indust.	10.689	14.166	9.720	4.211	.63113	.231645	.137221
Dayco Corp.	8.270	12.980	11.970	6.071	.30351	.666445	.030044
De Soto, Inc.	11.499	13.128	13.750	--	.72746	.272535	.000
Diamond Shamrock Corp.	9.790	13.721	9.720	--	.54639	.453615	.000
Dow Chemical	10.060	14.018	9.590	--	.56176	.438236	.000
Du Pont De Nemours	11.328	13.573	9.250	8.654	.72512	.232172	.042712
Eastern Gas & Fuel Associates	11.605	14.018	14.180	--	.63681	.363188	.000
Essex Chem. Corp.	12.502	14.166	12.395	--	.78453	.215465	.000
Exxon Corp.	11.875	13.276	9.250	--	.83450	.165504	.000
FMC Corp.	10.183	13.573	9.720	6.250	.59257	.339730	.067701

(continued)

TABLE E-2. (continued)

Name	Cost of capital	Return on equity	Return on debt[a]	Return on preferred stock[b]	Proportion of equity	Proportion of debt	Proportion of preferred stock
Ferro Corp.	12.369	13.276	9.720	--	.88968	.110317	.000
Firestone Tire & Rubber	10.610	12.980	9.720	--	.70096	.299038	.000
Ford Motor Co.	12.069	13.276	9.250	--	.85743	.142565	.000
GAF Corp.	9.398	13.573	10.380	7.559	.44490	.387035	.168061
General Electric Co.	12.130	13.721	9.250	--	.82148	.178521	.000
General Motors Corp.	12.798	13.425	9.250	8.715	.91962	.063516	.016862
General Tire & Rubber	11.440	13.276	11.970	--	.73287	.258968	.008163
Georgia-Pacific Corp.	10.793	13.573	9.590	--	.67625	.323751	.000
Goodrich (B.F.) Co.	10.430	13.276	10.380	8.864	.62957	.349707	.020723
Goodyear Tire & Rubber Co.	10.101	12.980	9.720	--	.63679	.363210	.000
Gulf Oil Corp.	11.745	12.980	9.250	--	.84880	.151203	.000
Hercules Inc.	11.177	13.869	9.720	--	.69461	.305394	.000
Inland Steel	10.092	12.980	9.590	--	.62702	.352735	.020249
Insilco Corp.	9.339	13.276	11.970	7.752	.41885	.475634	.105511
Interlake, Inc.	11.331	13.128	9.720	--	.77736	.222640	.000
International Harvester	10.534	13.573	9.720	--	.63297	.348230	.018796
Kaiser Steel Corp.	11.688	14.018	14.000	--	.63274	.345717	.021539
Kraft Inc.	10.774	12.683	9.250	--	.75752	.242479	.000
Marathon Oil Co.	9.582	13.128	9.720	--	.56074	.439257	.000
Martin Marietta Chem.	11.238	13.276	9.720	--	.75212	.247882	.000
Mead Corp.	10.000	13.869	9.720	4.308	.56423	.398718	.037048
Merck & Co.	12.309	13.573	9.250	--	.85481	.143358	.001827
Minnesota Mining & Manuf.	12.572	13.869	9.250	--	.85677	.143235	.000
Mobil Oil Corp.	10.868	13.128	9.250	--	.72833	.271665	.000
Monsanto Co.	10.970	13.573	9.590	5.000	.69690	.300335	.002767
Morton-Norwich Products	10.726	13.721	9.720	--	.65441	.345589	.000
National Distillers & Chem.	11.037	13.128	9.720	9.193	.73310	.251565	.015334
National Steel Corp.	9.909	12.683	9.590	--	.63946	.360538	.000
Northwest Indust.	8.015	13.869	10.380	2.9412	.32561	.617085	.057301

(continued)

TABLE E-2. (continued)

Name	Cost of capital	Return on equity	Return on debt[a]	Return on preferred stock[b]	Proportion of equity	Proportion of debt	Proportion of preferred stock
Owens-Corning Fiberglass	11.653	13.425	9.720	--	.78828	.211721	.000
PPG Industries	10.596	13.276	9.590	--	.67661	.323394	.000
Penwalt Corp.	9.013	13.276	9.720	7.529	.41712	.369200	.213675
Pfizer	11.244	14.018	9.590	--	.69289	.307113	.000
Phillips Petroleum Co.	11.670	13.721	9.250	--	.76982	.230179	.000
Procter & Gamble Co.	11.824	13.276	9.250	--	.82842	.171428	.000153
Quaker Oats Co.	10.946	13.573	9.720	9.008	.651578	.262094	.086328
Reeves Bros. Inc.	10.629	12.535	10.380	--	.732870	.267130	.000
Reichold Chems.	10.647	13.425	10.380	--	.571986	.295871	.132143
Republic Steel Corp.	11.305	13.425	9.720	--	.746819	.253181	.000
Riegel Textile Corp.	11.201	12.980	11.970	--	.736598	.263402	.000
Rockwell International	9.589	12.535	9.720	5.398	.602132	.309032	.088836
Rohn and Haas Co.	10.739	13.721	9.720	--	.655939	.344061	.000
SCM Corp.	10.835	14.018	10.380	--	.630766	.369234	.000
Scott Paper Co.	10.784	13.721	9.590	--	.660791	.333680	.005529
Shakespeare Co.	11.229	13.276	14.000	--	.658505	.341495	.000
Sherwin-Williams Co.	9.617	12.980	10.380	10.00	.523981	.422439	.053579
Squibb Corp.	11.266	14.018	9.590	--	.695345	.304655	.000
A. E. Staley Mfg. Co.	10.428	13.573	9.720	--	.629947	.368508	.001544
Stauffer Chemical Co.	10.188	13.425	9.720	--	.613351	.386649	.000
Sterling Drug	12.595	13.276	9.590	--	.917816	.082184	.000
Sun Chem. Corp.	10.427	13.573	12.395	--	.558689	.441311	.000
Sybron Corp.	10.786	13.869	9.720	--	.616191	.319517	.064292
Tenneco Inc.	9.155	12.980	10.380	3.887	.505890	.442129	.051981
Texaco	11.230	12.980	9.250	--	.785863	.214137	.000
Texfi Indust.	10.090	13.275	16.000	--	.356904	.643096	.000
Textron Inc.	10.085	13.425	9.720	6.222	.577353	.252757	.169890
Union Camp Corp.	11.359	13.276	9.590	--	.768639	.231361	.000
Union Carbide Corp.	10.775	13.573	9.590	--	.674170	.325830	.000
Union Oil, Calif.	10.577	13.128	9.590	--	.663994	.295934	.040072
Uniroyal	10.514	13.425	11.970	16.000	.521603	.423786	.054611
U.S. Gypsum	10.726	13.276	9.590	5.539	.686341	.223477	.090182
U.S. Steel Corp.	10.919	13.573	9.590	--	.690912	.309088	.000
Upjohn Co.	11.052	13.573	9.590	--	.706383	.293617	.000

(continued)

TABLE E-2. (continued)

Name	Cost of capital	Return on equity	Return on debt[a]	Return on preferred stock[b]	Proportion of equity	Proportion of debt	Proportion of preferred stock
Vulcan Materials Co.	10.675	12.980	9.720	--	.709218	.290782	.000
Walter (Jim) Corp.	9.019	13.721	11.970	4.444	.398726	.491966	.109308
Westinghouse Electric Corp.	12.596	14.018	9.720	8.837	.838775	.155115	.006110
Weyerhaeuser Co.	10.402	14.166	9.590	5.957	.583685	.357341	.058973
Wheeling-Pittsburgh Steel	11.238	13.869	14.000	12.739	.512893	.381136	.105972
Whittaker Corp.	10.070	14.314	11.970	--	.457808	.517470	.024722
Wit Chem. Corp.	10.736	13.573	9.720	3.313	.673790	.292825	.033385

[a] The return on debt data represent pretax estimates and are multipled by 0.52 to obtain the aftertax rates used in computing the cost of capital.

[b] Dashes indicate missing data. In these cases the pretax returns on debt were used to compute the cost of capital.

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APPENDIX E REFERENCES

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APPENDIX F - SYNTHETIC ORGANIC CHEMICALS MANUFACTURING INDUSTRY

OCPDB No.*	Chemical
20	Acetal
30	Acetaldehyde
40	Acetaldol
50	Acetamide
65	Acetanilide
70	Acetic acid
80	Acetic anhydride
90	Acetone
100	Acetone cyanohydrin
110	Acetonitrile
120	Acetophenone
125	Acetyl chloride
130	Acetylene
140	Acrolein
150	Acrylamide
160	Acrylic acid and esters
170	Acrylonitrile
180	Adipic acid
185	Adiponitrile
190	Alkyl naphthalenes
200	Allyl alcohol
210	Allyl chloride
220	Aminobenzoic acid

*The OCPDB Numbers are reference indices assigned to the various chemicals in the Organic Chemical Producers Data Base developed by EPA.

OCPDB No.	Chemical
230	Aminoethylethanolamine
235	p-aminophenol
240	Amyl acetates
250	Amyl alcohols
260	Amyl amine
270	Amyl chloride
280	Amyl mercaptans
290	Amyl phenol
300	Aniline
310	Aniline hydrochloride
320	Anisidine
330	Anisole
340	Anthranilic acid
350	Anthraquinone
360	Benzaldehyde
370	Benzamide
380	Benzene
390	Benzenedisulfonic acid
400	Benzenesulfonic acid
410	Benzil
420	Benzilic acid
430	Benzoic acid
440	Benzoin
450	Benzonitrile
460	Benzophenone
480	Benzotrichloride

OCPDB No.	Chemical
490	Benzoyl chloride
500	Benzyl alcohol
510	Benzyl amine
520	Benzyl benzoate
530	Benzyl chloride
540	Benzyl dichloride
550	Biphenyl
560	Bisphenol A
570	Bromobenzene
580	Bromonaphthalene
590	Butadiene
592	1-butene
600	n-butyl acetate
630	n-butyl acrylate
640	n-butyl alcohol
650	s-butyl alcohol
660	t-butyl alcohol
670	n-butylamine
680	s-butylamine
690	t-butylamine
700	p-tert-butyl benzoic acid
710	1,3-butylene glycol
750	n butyraldehyde
760	Butyric acid
770	Butyric anhydride
780	Butyronitrile

OCPDB No.	Chemical
785	Caprolactam
790	Carbon disulfide
800	Carbon tetrabromide
810	Carbon tetrachloride
820	Cellulose acetate
840	Chloroacetic acid
850	m-chloroaniline
860	o-chloroaniline
870	p-chloroaniline
880	Chlorobenzaldehyde
890	Chlorobenzene
900	Chlorobenzoic acid
905	Chlorobenzotrichloride
910	Chlorobenzoyl chloride
920	Chlorodifluoroethane
921	Chlorodifluoromethane
930	Chloroform
940	Chloronapthalene
950	o-chloronitrobenzene
951	p-chloronitrobenzene
960	Chlorophenols
964	Chloroprene
965	Chlorosulfonic acid
970	m-chlorotoluene
980	o-chlorotoluene
990	p-chlorotoluene

OCPDB No.	Chemicals
992	Chlorotrifluoromethane
1000	m-cresol
1010	o-cresol
1020	p-cresol
1021	Mixed cresols
1030	Cresylic acid
1040	Crotonaldehyde
1050	Crotonic acid
1060	Cumene
1070	Cumene hydroperoxide
1080	Cyanoacetic acid
1090	Cyanogen chloride
1100	Cyanuric acid
1110	Cyanuric chloride
1120	Cyclohexane
1130	Cyclohexanol
1140	Cyclohexanone
1150	Cyclohexene
1160	Cyclohexylamine
1170	Cyclooctadiene
1180	Decanol
1190	Diacetone alcohol
1200	Diaminobenzoic acid
1210	Dichloroaniline
1215	m-dichlorobenzene
1216	o-dichlorobenzene

OCPDB No.	Chemical
1220	p-dichlorobenzene
1221	Dichlorodifluoromethane
1244	1,2-dichloroethane (EDC)
1240	Dichloroethyl ether
1250	Dichlorohydrin
1270	Dichloropropene
1280	Dicyclohexylamine
1290	Diethylamine
1300	Diethylene glycol
1304	Diethylene glycol diethyl ether
1305	Diethylene glycol dimethyl ether
1310	Diethylene glycol monobutyl ether
1320	Diethylene glycol monobutyl ether acetate
1330	Diethylene glycol monoethyl ether
1340	Diethylene glycol monoethyl ether acetate
1360	Diethylene glycol monomethyl ether
1420	Diethyl sulfate
1430	Difluoroethane
1440	Diisobutylene
1442	Diisodecyl phthalate
1444	Diisooctyl phthalate
1450	Diketene
1460	Dimethylamine
1470	N,N-dimethylaniline
1480	N,N-dimethyl ether
1490	N,N-dimethylformamide

CCPDB No.	Chemical
1495	Dimethylhydrazine
1500	Dimethyl sulfate
1510	Dimethyl sulfide
1520	Dimethyl sulfoxide
1530	Dimethyl terephthalate
1540	3,5-dinitrobenzoic acid
1545	Dinitrophenol
1550	Dinitrotoluene
1560	Dioxane
1570	Dioxolane
1580	Diphenylamine
1590	Diphenyl oxide
1600	Diphenyl thiourea
1610	Dipropylene glycol
1620	Dodecene
1630	Dodecylaniline
1640	Dodecylphenol
1650	Epichlorohydrin
1660	Ethanol
1661	Ethanolamines
1670	Ethyl acetate
1680	Ethyl acetoacetate
1690	Ethyl acrylate
1700	Ethylamine
1710	Ethylbenzene

OCPDB No.	Chemicals
1720	Ethyl bromide
1730	Ethylcellulose
1740	Ethyl chloride
1750	Ethyl chloroacetate
1760	Ethylcyanoacetate
1770	Ethylene
1780	Ethylene carbonate
1790	Ethylene chlorohydrin
1800	Ethylenediamine
1810	Ethylene dibromide
1830	Ethylene glycol
1840	Ethylene glycol diacetate
1870	Ethylene glycol dimethyl ether
1890	Ethylene glycol monobutyl ether
1900	Ethylene glycol monobutyl ether acetate
1910	Ethylene glycol monoethyl ether
1920	Ethylene glycol monoethyl ether acetate
1930	Ethylene glycol monomethyl ether
1940	Ethylene glycol monomethyl ether acetate
1960	Ethylene glycol monophenyl ether
1970	Ethylene glycol monopropyl ether
1980	Ethylene oxide
1990	Ethyl ether
2000	2-ethylhexanol
2010	Ethyl orthoformate
2020	Ethyl oxalate

OCPDB No.	Chemical
2030	Ethyl sodium oxalacetate
2040	Formaldehyde
2050	Formamide
2060	Formic acid
2070	Fumaric acid
2073	Furfural
2090	Glycerol (Synthetic)
2091	Glycerol dichlorohydrin
2100	Glycerol triether
2110	Glycine
2120	Glyoxal
2145	Hexachlorobenzene
2150	Hexachloroethane
2160	Hexadecyl alcohol
2165	Hexamethylenediamine
2170	Hexamethylene glycol
2180	Hexamethylenetetramine
2190	Hydrogen cyanide
2200	Hydroquinane
2210	p-hydroxybenzoic acid
2240	Isoamylene
2250	Isobutanol
2260	Isobutyl acetate
2261	Isobutylene
2270	Isobutyraldehyde
2280	Isobutyric acid

OCPDB No.	Chemical
2300	Isodecanol
2320	Isooctyl alcohol
2321	Isopentane
2330	Isophorone
2340	Isophthalic acid
2350	Isoprene
2360	Isopropanol
2370	Isopropyl acetate
2380	Isopropylamine
2390	Isopropyl chloride
2400	Isopropylphenol
2410	Ketene
2414	Linear alkyl sulfonate
2417	Linear alkylbenzene
2420	Maleic acid
2430	Maleic anhydride
2440	Malic acid
2450	Mesityl oxide
2455	Metanilic acid
2460	Methacrylic acid
2490	Methallyl chloride
2500	Methanol
2510	Methyl acetate
2520	Methyl acetoacetate
2530	Methylamine
2540	n-methylaniline

OCPDB No.	Chemical
2545	Methyl bromide
2550	Methyl butynol
2560	Methyl chloride
2570	Methyl cyclohexane
2590	Methyl cyclohexanone
2620	Methylene chloride
2530	Methylene dianiline
2635	Methylene diphenyl diisocyanate
2640	Methyl ethyl ketone
2645	Methyl formate
2650	Methyl isobutyl carbinol
2660	Methyl isobutyl ketone
2665	Methyl methacrylate
2670	Methyl pentynol
2690	α-methylstyrene
2700	Morpholine
2710	α-naphthalene sulfonic acid
2720	β-naphthalene sulfonic acid
2730	α-naphthol
2740	β-naphthol
2750	Neopentanoic acid
2756	o-nitroaniline
2757	p-nitroaniline
2760	o-nitroanisole
2762	p-nitroanisole
2770	Nitrobenzene

OCPDB No.	Chemical
2780	Nitrobenzoic acid (o, m, and p)
2790	Nitroethane
2791	Nitromethane
2792	Nitrophenol
2795	Nitropropane
2800	Nitrotoluene
2810	Nonene
2820	Nonyl phenol
2830	Octyl phenol
2840	Paraldehyde
2850	Pentaerythritol
2851	n-pentane
2855	1-pentene
2860	Perchloroethylene
2882	Perchloromethyl mercaptan
2890	o-phenetidine
2900	p-phenetidine
2910	Phenol
2920	Phenolsulfonic acids
2930	Phenyl anthranilic acid
2940	Phenylenediamine
2950	Phosgene
2960	Phthalic anhydride
2970	Phthalimide
2973	β-picoline
2976	Piperazine

OCPDB No.	Chemical
3000	Polybutenes
3010	Polyethylene glycol
3025	Polypropylene glycol
3063	Propionaldehyde
3066	Propionic acid
3070	n-propyl alcohol
3075	Propylamine
3080	Propyl chloride
3090	Propylene
3100	Propylene chlorohydrin
3110	Propylene dichloride
3111	Propylene glycol
3120	Propylene oxide
3130	Pyridine
3140	Quinone
3150	Resorcinol
3160	Resorcylic acid
3170	Salicylic acid
3180	Sodium acetate
3181	Sodium benzoate
3190	Sodium carboxymethyl cellulose
3191	Sodium chloroacetate
3200	Sodium formate
3210	Sodium phenate
3220	Sorbic acid
3230	Styrene
3240	Succinic acid

OCPDB No.	Chemical
3250	Succinitrile
3251	Sulfanilic acid
3260	Sulfolane
3270	Tannic acid
3280	Terephthalic acid
3290 & 3291	Tetrachloroethanes
3300	Tetrachlorophthalic anhydride
3310	Tetraethyllead
3320	Tetrahydronapthalene
3330	Tetrahydrophthalic anhydride
3335	Tetramethyllead
3340	Tetramethylenediamine
3341	Tetramethylethylenediamine
3349	Toluene
3350	Toluene-2,4-diamine
3354	Toluene-2,4-diisocyanate
3355	Toluene diisocyanates (mixture)
3360	Toluene sulfonamide
3370	Toluene sulfonic acids
3380	Toluene sulfonyl chloride
3381	Toluidines
3390,3391 & 3393	Trichlorobenzenes
3395	1,1,1-trichloroethane
3400	1,1,2-trichloroethane

CCPDB No.	Chemical
3410	Trichloroethylene
3411	Trichlorofluoromethane
3420	1,2,3-trichloropropane
3430	1,1,2-trichloro-1,2,2-trifluoroethane
3450	Triethylamine
3460	Triethylene glycol
3470	Triethylene glycol dimethyl ether
3480	Triisobutylene
3490	Trimethylamine
3500	Urea
3510	Vinyl acetate
3520	Vinyl chloride
3530	Vinylidene chloride
3540	Vinyl toluene
3541	Xylenes (mixed)
3560	o-xylene
3570	p-xylene
3580	Xylenol
3590	Xylidine

APPENDIX G - UNCONTROLLED EMISSIONS ESTIMATES

TABLE G-1. UNCONTROLLED EMISSIONS ESTIMATES FROM THE MODEL UNITS[a]

Fugitive Emission Source	Uncontrolled Emissions					
	Model Unit A		Model Unit B		Model Unit C	
	kg/hr	% of Total	kg/hr	% of Total	kg/hr	% of Total
Pumps	1.1	14	4.08	14	12.78	14
Light liquid	0.96		3.48		10.92	
Heavy liquid	0.14		0.60		1.86	
In-line valves	2.76	36	11.11	38	34.14	37
Vapor service	1.89		7.66		23.46	
Light liquid service	0.84		3.35		10.37	
Heavy liquid service	0.025		0.10		0.31	
Safety/relief valves	1.78	23	6.78	23	21.0	23
Vapor service	1.76		6.72		20.8	
Light liquid service	0.006		0.024		0.078	
Heavy liquid service	0.009		0.036		0.13	
Open-ended valves and lines	1.03	13	4.14	14	12.75	14
Vapor service	0.225		0.925		2.88	
Light liquid service	0.66		2.65		8.13	
Heavy liquid service	0.14		0.57		1.74	
Compressors	0.44	6	0.88	3	3.52	4
Sampling Connections	0.39	5	1.56	5	4.80	5
Flanges	0.18	2	0.72	2	2.22	2
Total from all Fugitive Emission Sources	7.68		29.3		91.2	

[a] Calculated from the emission factors in Table 3-1 and the fugitive emission source counts in Table 6-1.